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COMING MEETINGS

Midwinter Convention, Philadelphia, Pa., February 4-8

Spring Convention, Birmingham, Alabama, April 7-11

Annual Convention, Evanston, Ill., June

MEETINGS OF OTHER SOCIETIES

American Association for the Advancement of Science, Cincinnati, Ohio, December 27 to January 2

American Institute of Chemical Engineers, Washington, D. C., December 5-8

American Physical Society, Annual Meeting, Cincinnati, Ohio, December 27-29

American Society of Mechanical Engineers, New York, N. Y., December 3-6

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Performance of Auto Transformers with Tertiaries Under Short-Circuit Conditions

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Review of the Subject.—*The problem of operating many of the present day transformers designed and built to function in sizes and under conditions unheard of only a few years ago, is now of prime importance to many of the larger power companies.*

A statement of one type of the operating troubles encountered in the larger sizes is discussed in this paper and data taken as far as practicable under operating conditions is given.

From experience so far gained it is thought that both the auto-transformer and the grounded neutral system are here to stay and such problems as they present merit considerable investigation under actual working conditions.

The present paper presents rather than solves one type of trouble encountered.

* * * * *

In July, 1914, the California Railroad Commission published the first report of the Joint Committee on Inductive Interference.

In 1918 General Order No. 52 superseded General Order No. 39, following the final report of the same committee. In this order under which California public utilities now operate is the following clause, "no star-connected transformers or auto transformers shall be employed with a grounded neutral on the side connected to a three-phase power circuit involved in a normal parallel, unless low-impedance, delta-connected secondary or tertiary windings or equivalent means are used for suppressing the triple harmonic components of the residual voltages and currents introduced by the transformers".

In complying with this order, and to reduce the cost on a winding used solely to suppress the effects of causes which could not be removed, most companies have used tertiary windings of capacity less than the rating of the transformers, that is, the current-carrying capacity of the tertiary winding has been reduced by reducing its copper cross-section.

At the same time most of the major companies using high-tension systems in California have adopted a permanently grounded neutral on the high-tension circuit and a considerable number of the later-built transformers have been auto transformers, designed specifically to operate only with one terminal of the high-voltage winding grounded.

In present designs some of the tertiaries have a current density 20 per cent higher than the primary of the same transformer for the nameplate rating. This relatively high resistance further increases the tertiary temperatures under short-circuit conditions. Having this condition in mind it becomes an operating problem of when and how to protect the tertiary winding against destructive overheating during line short circuits.

Tertiary windings are used, in addition to the prevention of inductive interference, for:

1. Providing a path for the flow of third harmonic current, necessary for the proper magnetization of the core for a sine wave e. m. f. across the main windings.

2. Stabilizing the neutral and providing a sufficient flow of current in the line-or windings at times of single-phase short-circuit conditions to give proper operation of relays and circuit-breakers.

3. Providing a winding for load connections or a synchronous condenser.

In practise the size of the tertiary is fixed by the short-circuit kv-a. rather than the third harmonic component of magnetizing current, *i. e.*, this winding must carry the short-circuit kv-a. long enough to allow circuit opening devices to operate. The time required to open the circuit is usually short, of the order of 5 seconds or less, and therefore very little radiation of heat takes place, consequently the copper must store its $I^2 R$ losses by thermal capacity during this period.

There is given later a curve for determining approximately the relations of size of copper, current, temperature, and time for this condition.

For short-circuit conditions, the size of the tertiary is determined by the value of short-circuit current that it is desirable for protective reasons and the duration of the heavy current.

From 300 per cent to 400 per cent of normal current is usually desired for operation of protective relays and this abnormal current requires a tertiary winding constructed to have from 25 to 30 per cent of the capacity of the main transformer windings.

The reactance in the tertiary circuit is then made such as to limit the current to the above values for the voltage applied to a short-circuited transformer.

It is unsafe to use less reactance on account of danger from burnout and not wise to use more because the amount of the short-circuit current desired would not be obtained.

The kw. capacity and reactance of the tertiary are interdependent and with one value given the other is fixed.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.

In operation a few specific schemes only are of interest because, for operating reasons, only certain connections are used; and odd or infrequent connections if determining the design characteristics, should be treated as special cases, as should all cases where a synchronous condenser operates from a tertiary.

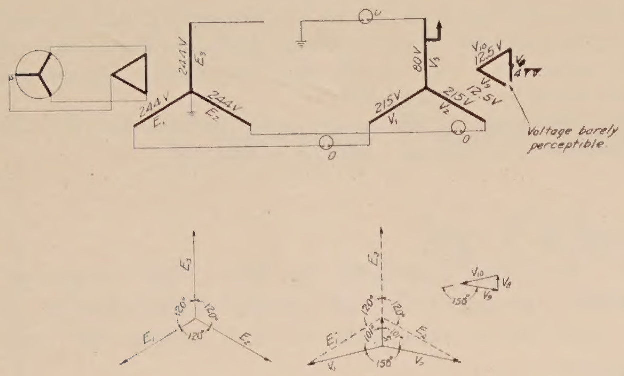

FIG. 1

Rating
Primary: 1500 kv-a., 40,000 volts
Secondary: 1500 kv-a., 6680 volts
Tertiary: 300 kv-a., 2340 volts
Impedance: Primary and Secondary: 5.7 per cent at 1500 kv-a.
Impedance: Primary and Tertiary: 20 per cent at 1500 kv-a.

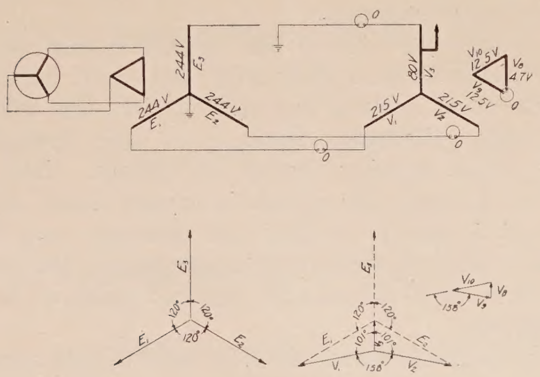

FIG. 2
For rating of transformer, see Fig. 1

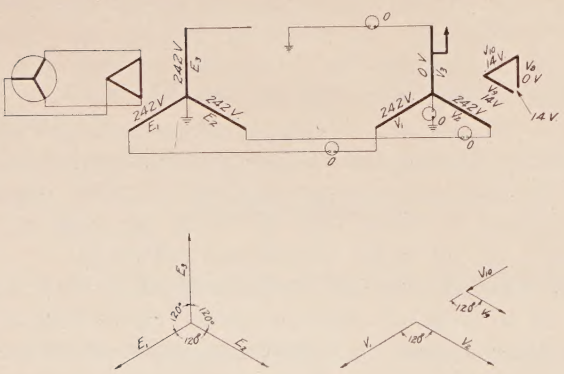

FIG. 3
For rating of transformer, see Fig. 1

To show approximately what takes place for different transformer connections a bank of transformers having a tertiary was tested at less than normal voltage and the several voltages and currents read as shown in the following figures.

Fig. 1 shows a ground on the high-tension with the neutral ungrounded tertiary closed.

Fig. 2 shows the tertiary open.

Fig. 3 shows the neutral grounded tertiary open.

Fig. 4 tertiary closed.

Figures 5, 6 and 7 show Y-Y-connected transformers with a tertiary and grounds on the secondary side.

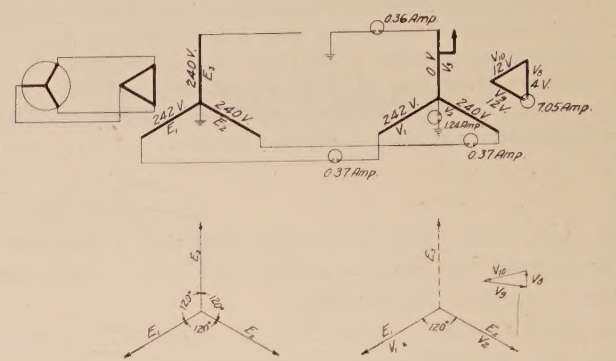

FIG. 4
For rating of transformer, see Fig. 1

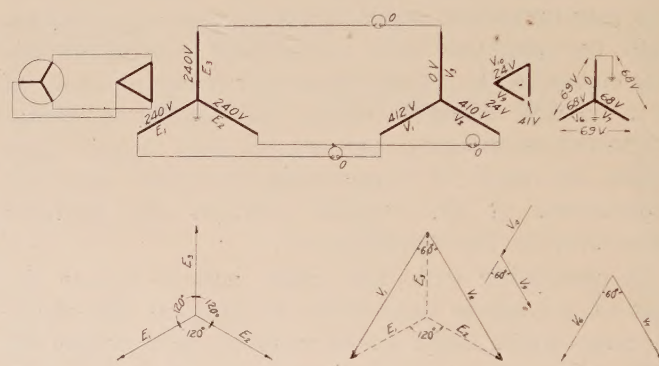

FIG. 5
For rating of transformer, see Fig. 1

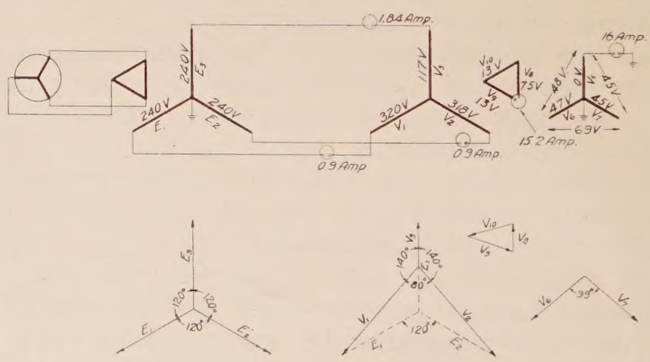

FIG. 6
For rating of transformer, see Fig. 1

Figures 8, 9 and 10 and 11 show conditions in auto transformers with a tertiary.

These figures are self explanatory and indicate clearly what takes place on short-circuit conditions. Not all of the connections are used in practise, but from a study of the diagrams given in the several figures an idea can be gained as to what happens in practise.

Fig. 12 gives a curve from a bank of transformers in which the tertiary has a rating of 20 per cent of the transformer rating, and an impedance such that, with the tertiary short-circuited, from 15 to 20 per cent of full voltage is required to circulate full current through the high-voltage winding. For this test one high-voltage winding was short-circuited and gradually increasing 3-phase voltage applied, measuring the current in the tertiary and short-circuited high-voltage winding. For 300 per cent high-voltage current there will flow approximately 14½ times normal current in the tertiary.

Fig. 13 gives a curve for the heating of the transformer windings neglecting radiation and using the 60 deg. cent. resistance of copper. From the study of this and similar data it was decided to install, on a bank of three 12,000-kv-a., 110-kv., 60-kv., Y-connected auto transformers a 13,800-volt tertiary having a capacity of 4000 kv-a. in each, of 13 per cent impedence

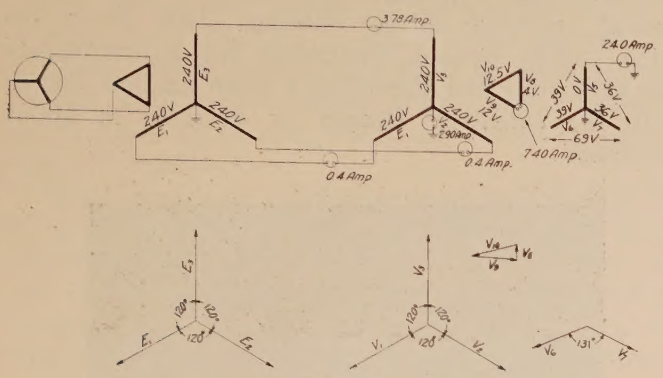

Fig. 7

For rating of transformers, see Fig. 1

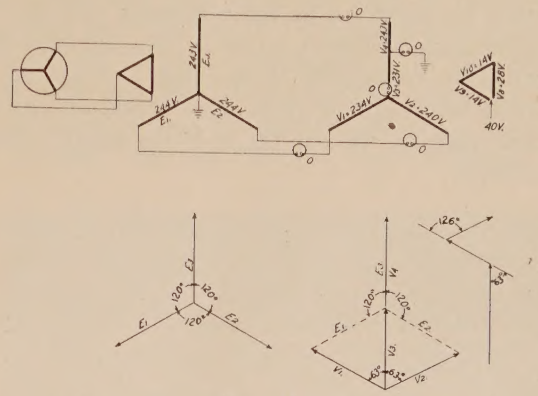

Fig. 10

For rating of transformers, see Fig. 8

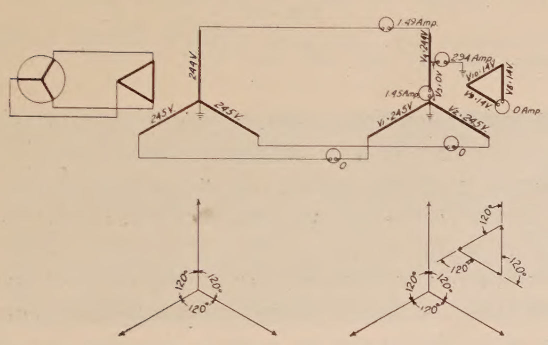

Fig. 8

Rating

Primary: 1500 kv-a., 40,100 volts

Secondary: 1500 kv-a., 6680 volts

Tertiary: 300 kv-a., 2340 volts

Impedance: Primary ϵ, Secondary: 5.7 per cent at 1500 kv-a.

Impedance: Primary ϵ, Tertiary: 20 per cent at 1500 kv-a.

Connected as auto transformer. Tap in exact center of primary winding.

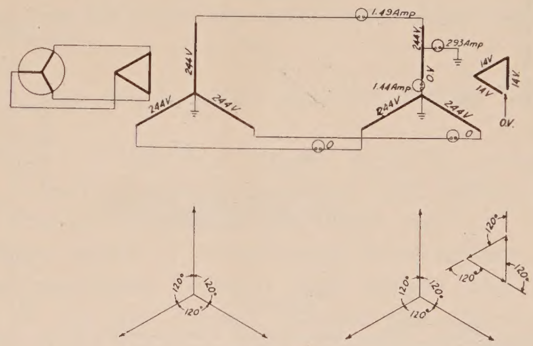

Fig. 11

For rating of transformers, see Fig. 8

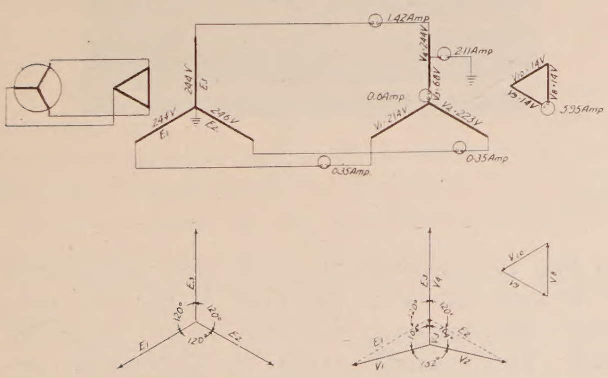

Fig. 9

For rating of transformers, see Fig. 8

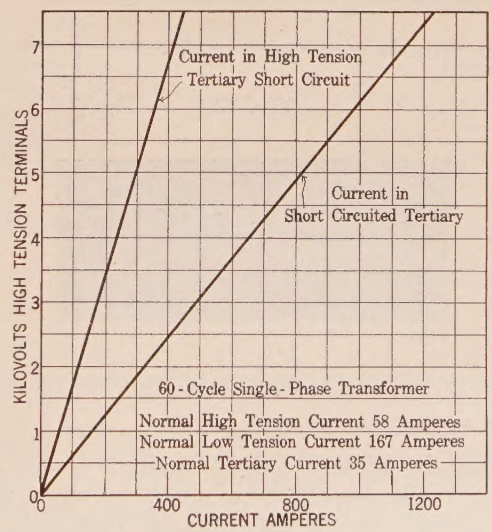

Fig. 12

and a relay in the tertiary to open it in case of sustained overload.

Later a 12,500-kv-a., 13,200-volt synchronous condenser was so connected as to operate on this tertiary that when the tertiary switch opened it cleared the condenser by means of its main running switch. This developed considerable trouble in the tertiary switch and winding apparently from high voltage so that a series of short-circuit tests were made on the bank and oscillographic records taken of the tertiary current and voltage.

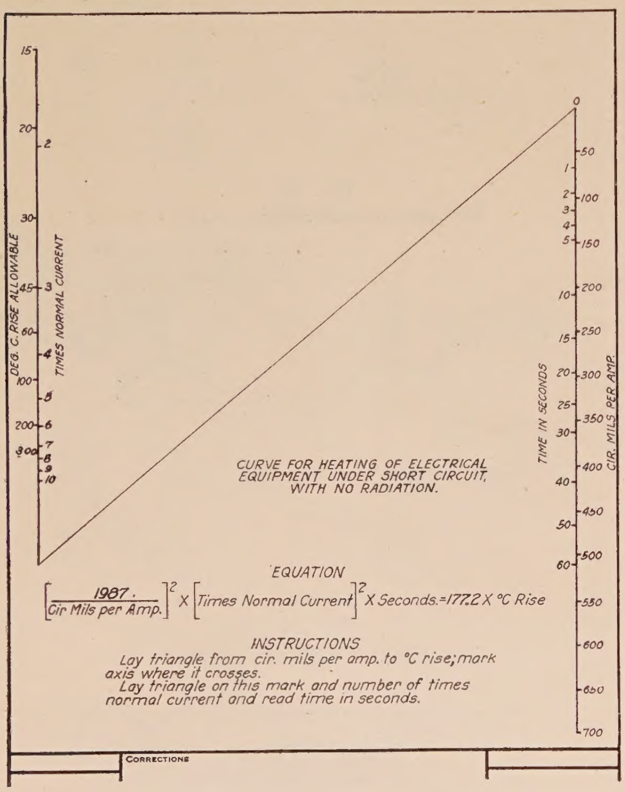

Fig. 13

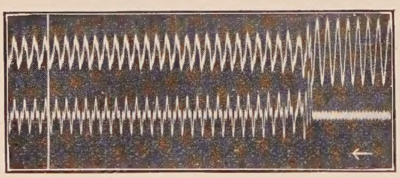

Fig. 14
Volts to ground on top; volts across tertiary on bottom; tertiary current in center

By using a comparatively long 100-kv. line with a limited amount of available power it was possible to short-circuit the 60-kv. side of one auto transformer to ground.

Fig. 14 gives a curve of the voltage from one condenser lead *i.e.* one corner of the delta to ground together with the tertiary current when one phase of the 60-kv. was grounded.

There is shown a somewhat violent change in tertiary current for the first 1½ cycles after the short circuit occurred from the usual triple harmonic magnetizing current to a badly peaked 60-cycle wave which then continues as long as permanent short-circuit conditions remain.

Fig. 15 shows the 60-kv. ground thrown on with the condenser drawing approximately 30 per cent normal armature current leading. This shows the same violent current fluctuation for approximately the same time and thereafter a more gradual change until the condenser cleared by overload in about ½ second.

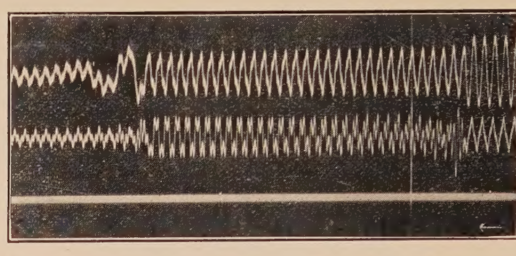

Fig. 15
Volts to ground on top; volts across tertiary on bottom; tertiary current in center

This tertiary current wave form during short circuit shows the effect of the condenser as compared with the normal running conditions at the start and the short-circuit conditions without the condenser at the latter end of the film.

The voltage from one corner of the delta to ground changes as the short circuit was applied from an approximate sine wave to a wave showing the effects of the disturbed magnetic conditions and finally as the condenser clears to the static voltage of the winding to ground.

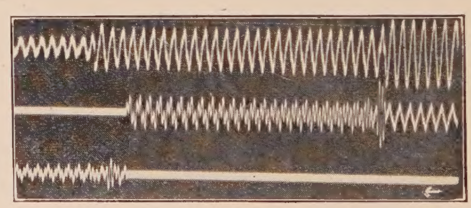

Fig. 16
Volts to ground on top; volts across tertiary on bottom: tertiary current in center

In Fig. 16 the condenser boost was raised until it was drawing somewhat less than 25 per cent normal current (532 amperes) with the 60 kv. grounded as before. The transient changes for the first few cycles are the same, but this test was so arranged that the tertiary relay opened the tertiary switch which in turn tripped the main condenser switch as in normal operation.

For about 4 cycles between the time of opening of the tertiary switch and the clearing of the condenser there appears a badly distorted voltage of some 4500 volts across the tertiary switch.

Fig. 17 is the same with an added load on the condenser and shows a little more clearly the action between the time of opening the tertiary switch and clearing the condenser.

The values shown are not alarming except as they show abnormal characteristic tendencies. The short-circuit current was limited by limiting the supply to a very small fraction of what would normally be available and it is very difficult if at all possible to predict what would happen with current values 10 to 15 times those used which are known to exist in times of trouble.

There would also probably be a more violent disturbance for a ground on the 100-kv. fed from a 60-kv. source but the system connections were such that the supply could not be limited and it was not attempted. A ground was however thrown on the 100-kv. line without any other source than the 100-kv. itself and shows the same characteristics as regards sudden magnetic and current changes in the first two cycles. This is shown in Fig. 18 which shows the initial transient clearly.

The tertiary in this case did not trip, and, as it was

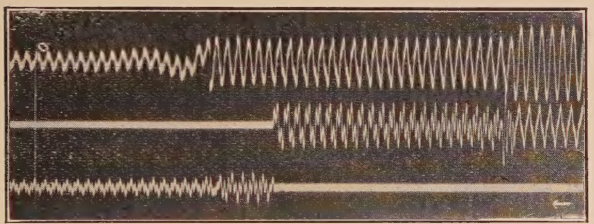

Fig. 17

Volts to ground on top; volts across tertiary on bottom; tertiary on bottom; tertiary current in center

impractical to feed from the 60-kv. as in normal conditions, no further tests were made.

It has been noted above that the currents used were only a small fraction of the values usually encountered in trouble though applied to full sized apparatus under working conditions.

It seems very difficult to work with miniature test apparatus and apply the results to full scale working conditions because of the difficulty of securing the same characteristics in each case.

From a study of the conditions encountered it was thought that it would be advisable:

1. To permanently close the tertiary, leaving its current transformer in service.

2. Connect the tertiary relay so that it clears the 100-kv. and 60-kv. transformer bank switches at about 300 per cent normal current in the tertiary in approximately 10 seconds.

3. This presupposes that the line protective switches are to operate as they have in the past to clear trouble selectively in about two seconds.

In the original scheme where the tertiary opened and tripped the synchronous condenser all of the switches were opened during the first ½ second after a short circuit occurred, that is on the definite time portion of the induction type relay curve.

It seems advisable to delay the action until the high-current values had subsided to more nearly a steady state and then clear the bank of transformers completely as a last resort. On banks of transformers in which the tertiary impedance is in the order of 20 per cent and the current-carrying capacity 25 per cent or above, with a primary impedance of 5 per cent it is thought that the tertiary will withstand for a

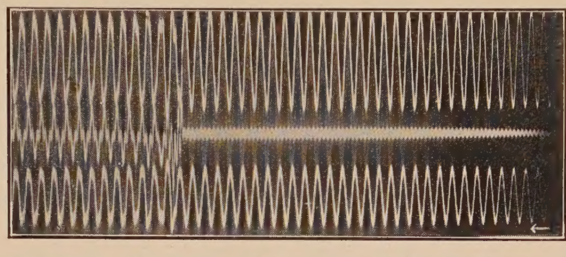

Fig. 18

Top, phase B-A tertiary volts; middle, tertiary current; bottom, phase A volts ground.

short time any overload that the primary can withstand.

Such combinations, unless supplying condensers, can be and usually are treated as delta banks and only the over-all transformer protection used.

Some banks of transformers have neither 20 per cent impedance between high tension and tertiary nor 25 per cent tertiary current capacity and these installations present a difficult problem in operation.

Important information on the subject of tertiary windings may be found in the following articles:

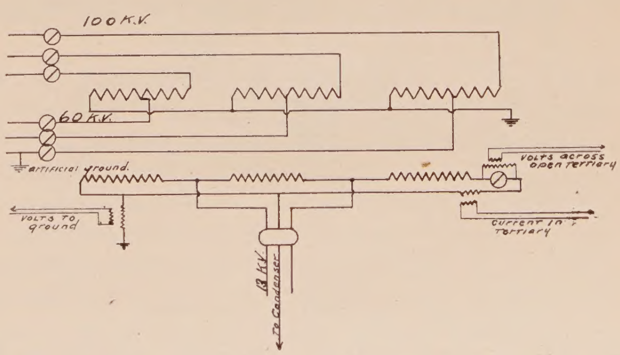

Fig. 19—Diagram of Connections

"Harmonics in Transformer Magnetizing Currents" by Mr. J. F. Peters, Transactions A. I. E. E. 1915.

"Tertiary Windings in Transformers, their Effects on Short-Circuit Current" by Mr. J. F. Peters, Electric Journal, Nov. 1919.

"Transformers for Interconnecting High-Voltage Transmission Systems; for Feeding Synchronous Condensers from a Tertiary Winding" by Mr. J. F. Peters and Mr. M. E. Skinner, June 1921, Journal of A. I. E. E.

Economic Considerations of the Power Factor Control of Long High-Voltage Lines

BY A. V. JOSLIN

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Review of the Subject:—*In the early days of the electric industry when transmission lines were short, power factor control was not considered necessary. At the present time, with transmission lines of 200 miles and more, and with loads whose power factor is very poor owing to the universal use of the induction motor, power factor control is being forced upon the transmission engineer as a necessity if power is to be transmitted economically.*

By taking a few typical examples of transmission lines, the effect of power factor upon efficiency of transmission is shown very clearly. The most economical line power factor for any ordinary commercial transmission line is shown to vary by a comparatively small per cent and to be slightly less than unity. At the same time there appears a very wide range of load delivered over a line without an undue rise in cost of transmission.

It is quite generally accepted that some degree of power factor correction is advisable over long high-voltage lines but the amount of this correction has been considered a special problem to be worked out for each particular line.

By constructing curves of kilowatt capacity and capital cost at various power factors for several typical lines, the writer has endeavored to show that the power factor for lowest transmission cost varies through a narrow range.

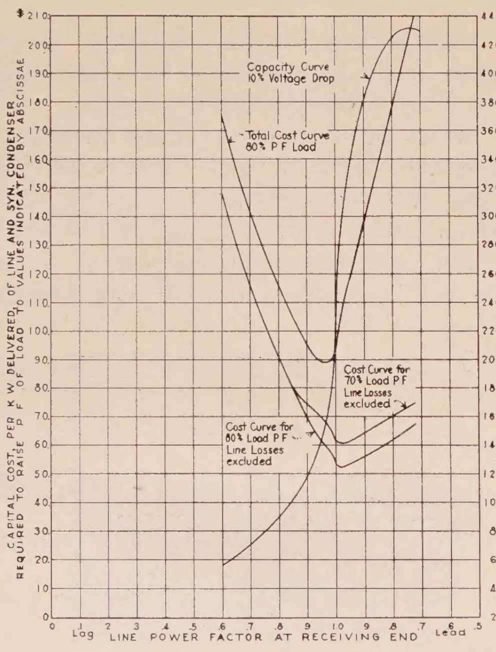

FIG. 1—COST AND CAPACITY CURVES—LINE A 200 MILES, 200 KW. 500,000 CIR. MILS COPPER, 10 PER CENT VOLTAGE DROP

The lines taken as typical are the following:

a. 200 miles, 2 circuit tower line, 500,000-cir. mil copper conductor, 200-kv. at receiving end, 10 per cent drop in voltage, 5 per cent transformer reactance at receiver end. Cost per mile, $35,000.

b. 100 miles, 2 circuit tower line, 250,000-cir. mil copper conductor, 100-kv. at receiving end, 10 per cent drop in voltage, 5 per cent transformer reactance at receiver end. Cost per mile, $15,000.

c. 50 miles, 2 circuit tower line, 250,000-cir. mil. copper conductor, 100-kv. at receiving end, 5 per cent drop in voltage, 5 per cent transformer reactance at receiver end. Cost per mile, $15,000.

Figs. 1, 2 and 3 each has a curve showing the kw. capacity of the different lines as the power factor at the receiving end varies. It will be noticed that the kw. capacity rises very rapidly around unity power factor.

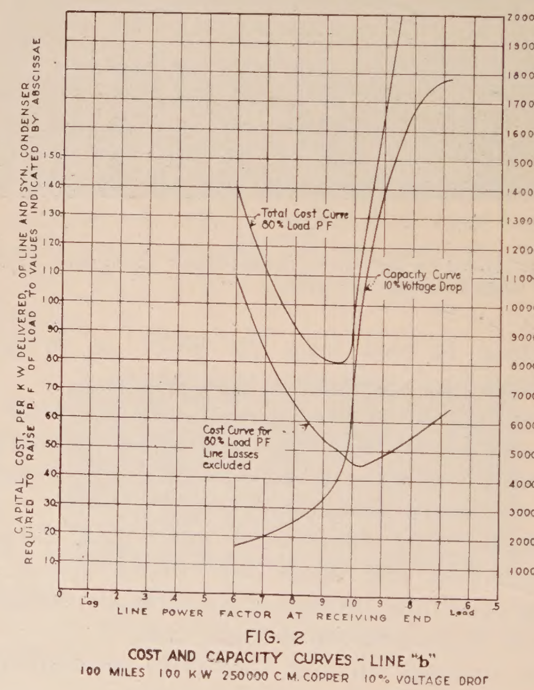

FIG. 2—COST AND CAPACITY CURVES—LINE B 100 MILES, 100 KW., 250,000 CIR. MIL COPPER, 10 PER CENT VOLTAGE DROP

Fig. 4 shows curves of capital invested per kw. delivered over line *a*. Curve marked "Line Cost" shows capital investment in line only. Curve marked "Condenser Cost" shows capital investment in synchronous condensers required to bring the load power factor, assumed to be 80 per cent, to the line power factor which

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is required for transmitting the load at the designated voltage drop.

"Condenser Cost" covers condensers installed on transformers necessarily in use for other purposes, and includes condenser losses at 3 per cent and at 4 mils per kw-hr. and depreciation at 3 per cent all capitalized at 6 per cent per annum. Itemized as follows:

Synchronous condenser installed per kv-a.	= $9.00
Power required to operate at 3 per cent loss for one year = 0.03 × 8760 = 262.8 kw-hr. 262.8 kw-hr. at $0.004	= $1.05
Depreciation at 3 per cent on $7.00	= .21
Cost of operating power and depreciation	$1.26
Capitalized at 6 per cent per annum	= 21.00
Total condenser cost per kw. delivered	= $30.00

Line and condenser cost curve is the sum of these two curves.

Line loss cost curve shows the $C^2 R$ line losses per kw-hr. capitalized at 6 per cent per annum.

Total cost curve is the sum of all the above costs.

Two of these curves, total cost and line and condenser costs are shown in Fig. 1 plotted to line power factor as abscissas in place of kw. delivered.

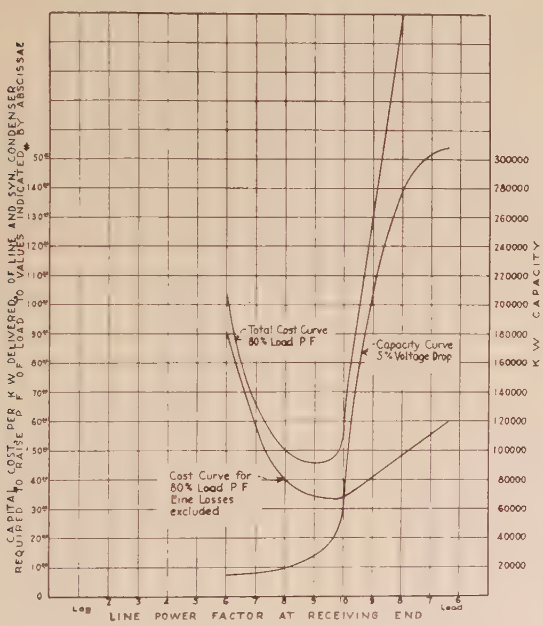

Fig. 3—Cost and Capacity Curves—Line C 50 Miles, 100 Kw., 250,000 Cir. Mil Copper, 5 Per Cent Voltage Drop

Total cost curve shows that, for a minimum transmission cost on this line, the line power factor should be about 97 per cent lagging.

Similar curves are shown in Figs. 2 and 3 for lines *b* and *c*. They indicate that for minimum transmission costs the line power factors should be about 95 per cent and 91 per cent lagging respectively.

Fig. 5 shows curves of line *b* at two different line drops; 0 per cent, and 15 per cent, which indicate the marked effect these differences have on the most economical line power factor.

Fig. 1 has a second cost curve with line losses excluded for a load power factor of 70 per cent. Comparing it with the 80 per cent load power factor show that the load power factor has a very slight effect on the most economical line power factor.

An increase in the size of conductor chosen will decrease the line loss cost curve and increase the line cost curve to a less degree; the net result being to

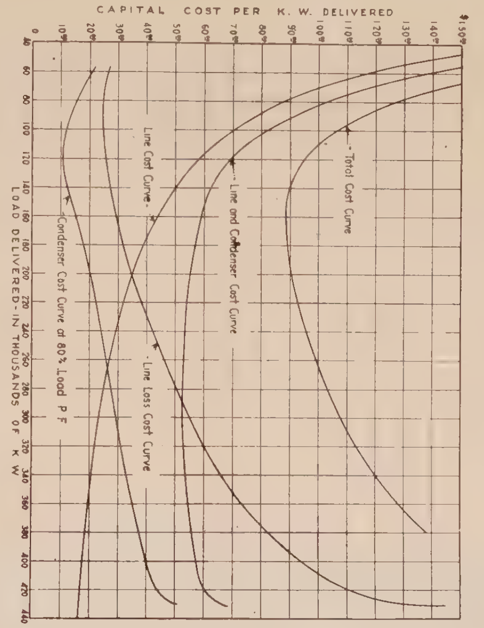

Fig. 4—Cost Curves per Kw. Delivered—Line A 200 Miles, 200 Kw., 500,000 Cir. Mil Copper, 10 Per Cent Voltage Drop, 80 Per Cent Load Power Factor.

raise the economical line power factor. This increase of the power factor is small compared to the corresponding increase of conductor required to produce it.

A smaller assumed cost of power will reduce the line loss cost curve and also the condenser cost curve, thus increasing the economical line power factor. A larger allowable voltage drop over the line will have a marked influence in raising the economical line power factor by reducing the condenser capacity required to deliver a stated amount of power.

Some of the smaller factors such as attendance for operating condensers have been neglected as well as the advantage gained by voltage regulation obtained by use of the condensers, which displaces regulation by induction regulators or other regulators with their attendant losses. Also the saving in generator size and losses due to the use of condensers has been neglected.

The foregoing considerations have all been based on a 100 per cent load factor which unfortunately is not often met with. However, by taking a load which will

give the average losses of the real load the above considerations will apply very closely The condenser capacity required would be enough greater to maintain the proper voltage at the peak load. The condenser losses would be only slightly greater. The condenser cost would be materially increased but this is roughly only about one third of the "condenser cost."

While the economy of transmission changes very rapidly with a small change in line power factor it changes very slowly over a wide range of kw. delivered, on both sides of the minimum cost point. This can be clearly seen in the "total cost curve," Fig. 4.

A change of load delivered from 125,000 kw. to 225,000, *i. e.* from 91 per cent power factor to unity means only a change in capital cost per kw. delivered of $4.50. Assuming an interest depreciation and operation charge of 12 per cent this means 54 cents per

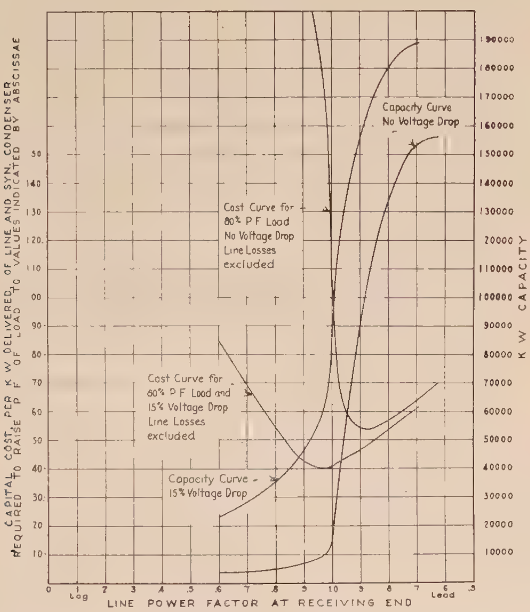

Fig. 5—Cost and Capacity Curves—Line B

8760 kw-hr. or about 0.06 mil. per kw-hr. which is a very small per cent of the total cost of a kw-hr.

It is a very happy circumstance that there is this wide range of load over which the transmission cost is near the minimum. It means that considerable increase of load can be allowed for when designing a new line without sacrificing present economy. Likewise the load on an existing line can be taken care of economically up to the point where it will justify an additional line.

Conclusion

On long high-voltage transmission lines it is economy to install synchronous condensers to correct the line power factor very close to unity and if it is necessary to correct slightly more than this on account of voltage regulation the economy of the transmission line will not be greatly effected.

STANDARDS OF RADIATION INTENSITY

For a number of years the Bureau has been investigating the instruments and methods used in radiometry, and during the past nine years it has provided investigators with standards of radiation intensity in absolute value. These radiation standards are of use to biologists, physiologists, psychologists, and others, to standardize the light stimuli employed in their investigations. In this way the work throughout the country is becoming systematized and specified on a reproducible basis.

During the past year there has been a greatly increased demand for these radiation standards, which consist of seasoned carbon filament incandescent lamps calibrated for radiation intensity (radiant power in watts per sq. mm. at a given distance from the lamp) when the lamp is operated on a given energy input. Last month considerable time was spent in comparing several dozen newly prepared radiation standards with the primary standards of the Bureau. The comparison is made by means of a thermopile in connection with a d'Arsonval galvanometer. The results obtained from day to day are in agreement to within 0.1 to 0.2 per cent. An interesting observation is the constancy of the galvanometer deflection. For a period of over five days, on resetting a certain primary standard and operating it on a given energy input, the scale distance and radiometer (galvanometer and thermopile, in air) remained so constant that the same galvanometer deflection was obtained to within 0.5 per cent.

THE VISIBILITY OF RADIANT ENERGY

In a study of the efficiency of light sources it is important to know the extent to which the eye is affected by light of different wave lengths, or the luminous efficiency of the spectrum. This factor varies somewhat with different individuals, so it is necessary to make observations on as many people as possible and to use the average of the results.

Several determinations of this average visibility have been made in the past, but rather large discrepancies appeared between the results of different observers. The National Lamp Works of the General Electric Company considered the subject of sufficient importance to cooperate with the Bureau of Standards in a new determination of the average visibility curve. Fifty-two observers were used in the measurements. As a result of this and previous investigations the visibility curve for the average observer is now known with sufficient certainty for all ordinary purposes.

These results are embodied in Scientific Paper No. 475 of the Bureau of Standards entitled "The Visibility of Radiant Energy."

High-Voltage Switches, Bushings, Lightning Arresters

Experiences of the Southern California Edison Company on its 60,000, 150,000 and 220,000-Volt System

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Review of the Subject.—*This paper describes the experiences of the Southern California Edison Company with oil switches on its 60-kv., 150-kv. and 220-kv. systems, with air break switches on its 220-kv. system, with bushings on its 60-kv., 150-kv. and 220-kv. systems, and with lightning arresters on all voltages from 11 kv. up.*

In some instances the experiences do not lead to unquestionable conclusions. This is particularly true in the case of lightning arresters. More nearly complete information in regard to actual occurrences will aid in drawing definite conclusions.

* * * * *

Switches

FOR many years the Southern California Edison Co. has been equipping its 60-kv. system very largely with western made oil switches. As the system has grown it has been necessary to increase the capacity of these switches. The first switches were made with three rectangular tanks, each tank having two horizontal breaks in series. The next step consisted of increasing the size of each rectangular tank and putting four breaks in series. And now we are installing switches, each consisting of three cylindrical tanks with round top and bottom and each tank having six or ten horizontal breaks in series. The rupturing capacity of these switches has never been known, but they have handled the job with a fair degree of satisfaction. Of course, the changes in design have been forced by increases in system capacity, which have proved the type in use to be inadequate. And it is not known how long the present type will be adequate.

In addition to the switches of local manufacture there are a considerable number of 60-kv. switches on the system which were furnished by eastern manufacturers. These switches, in general, have given good results, but it seems impossible to draw any reasonable conclusions in regard to whether the performance of the locally made switch is better or worse than the eastern made switches.

It would be very desirable to make comparative tests of oil switches under conditions similar to those under which the switches operate, but these tests would be very difficult to arrange.

It seems quite certain, however, that the capacity of the 60-kv. system can not be indefinitely increased. Although it may be physically possible to make oil switches which would not blow up when opening automatically under severe short circuits, their cost would be greater than the earnings would justify. This situation will probably be avoided by dividing the system into two or more partial systems and by the judicious use of the current-limiting reactors.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.

The 150-kv. oil switches on the Big Creek system have given good satisfaction as non-automatic switches. The method of operation has been such that automatic opening has not been required. The greater number of these switches have been in operation since 1913. They were furnished by two large eastern manufacturers.

The 220-kv. oil switches which were put into operation at 220-kv. on May 6th, 1923, have not been allowed to operate automatically up to the time of writing (June 20th, 1923). However, it is intended that

Fig. 1

they shall operate automatically to drop out a section of line which may be in trouble.

These switches were furnished by two large manufacturers. Aside from minor defects due to careless workmanship, or careless details of design, these switches have given satisfaction during the brief period they have been in operation.

There are three types of air brake switches in use on the 220-kv. system, namely, disconnecting switches for the oil switches; line-sectionalizing switches, and line-paralleling switches, the two latter types being used at line crossover stations other than those equipped with oil switches.

The disconnecting switches on either side of the 220-kv. oil switches are mounted on the tops of insulator tripods which in turn are carried on the top of steel frame-work. (See Fig. 1). Each leg of the

tripod consists of fourteen insulator units and has a total length of seven feet. The insulator unit is made up by cementing pillar type hardware to the porcelain of a standard 10-in. suspension insulator and the units are bolted rigidly together.

The switch blade is 10 ft. 6 in. long from the hinge to the jaw end and is composed of two pieces of 1¼-in. copper pipe joining at the jaw end and spread apart at the hinge end. The blade also extends back of the hinge to form a lever to which the operating rod is attached. The jaws are solid without any spring. The contact part of the blade is formed of two paralled copper straps which have considerable spring in them. These copper straps are drawn together or forced apart by a cam mechanism which in turn is operated by a rod which extends above the blade of the switch, past the hinge end to the operating rod. The operating rod consists of a fourteen-unit pillar type insulator and a rod extending to the ground, where a bell crank and operating handle complete the mechanism.

In opening the switch the first few inches of movement of the operating handle pulls the blade straps

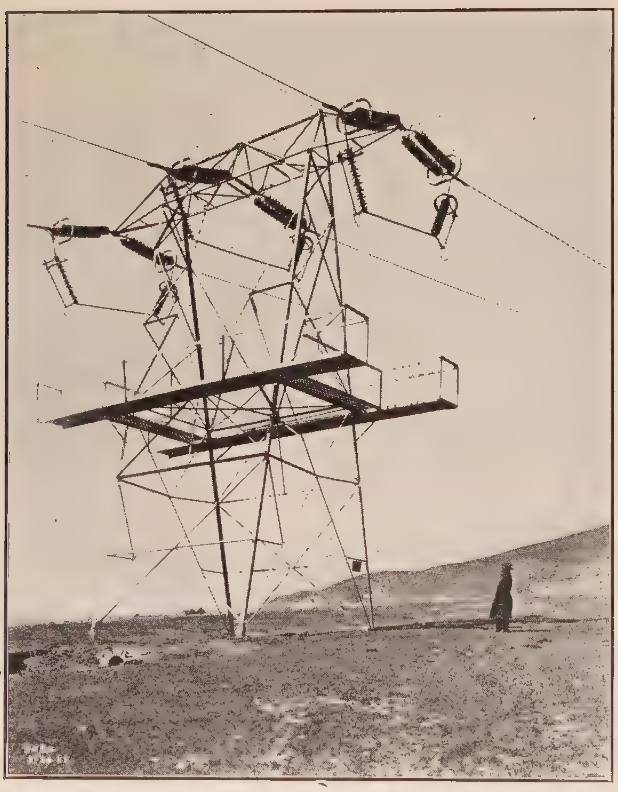

Fig. 2

together enough to free the blade in the jaws. Further movement of the operating handle swings the blade upward. In closing, the blade reaches its closed position and then the last few inches of travel of the operating handle forces the blade straps out against the jaws. The blade is counterweighted to make the operation easy. The clear opening of the switch is approximately 8 ft. 1½ in.

The line-sectionalizing switches take the place of the jumper loops in a dead-end tower and are in reality two switches in series, each switch blade when closed short-circuiting a string of eight pillar type insulators, the string length being about 4-ft. (See Fig. 2). This gives two 4-ft. openings between a live section and a dead section of line.

These switches are not to be operated except when

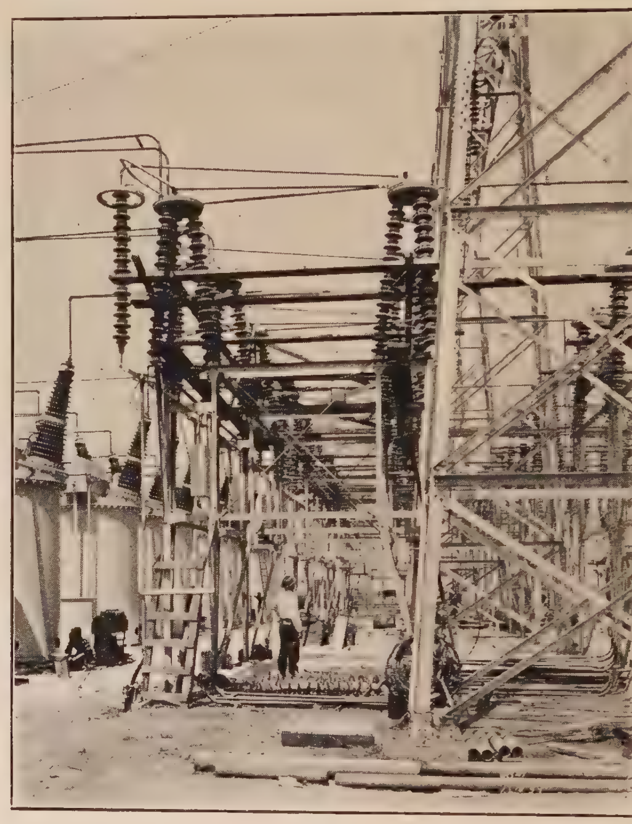

Fig. 3

the line is dead. The operating is done by means of a switch pole from a platform built into the tower.

The paralleling switch, Fig. 3, is placed between the lines with a set of sectionalizing switches in each line on each side of it, thus making four sets of sectionalizing switches and one set of paralleling switches for each crossover station.

Each single-pole paralleling switch consists of a pipe switch blade which bridges across a horizontal diamond of four strings of strain insulators (standard suspension insulators). The grounded corners of this diamond are supported on steel poles. The other corners are carried by the conductor of the crossover connection. The switch is operated through a 6-ft. column of twelve pillar-type insulators and a rod reaching to a bell crank and operating handle located on the ground. The switch blade opens upward and will break the current passing across it when the lines are still in parallel at another point, provided that the wind is not blowing too hard. In one instance when the wind was blowing hard the arc went to ground on the

supporting structure, doing no more physical damage than the breaking of the porcelain on one insulator unit and the burning of one shield ring.

Bushings

The question of bushings for the 60-kv. oil switches of local manufacture is rather simple, for the reason that the bushing does not support any part of the switch mechanism. Two of the insulator manufacturers make bushings which will fit these switches and they are giving very good results. The other 60-kv. oil switches as well as the 150-kv. and 220-kv. oil switches must have bushings made particularly for those switches, since the stationary contacts are carried by the bushings.

On the 150-kv. and 220-kv. apparatus there are the oil-filled bushings, or compound-filled on the older equipment, and the condenser type bushings. There have been a few cases of breakdown on both types. The compound-filled bushing is in general disrepute and the transformers which originally had compound-filled bushings are now equipped with oil-filled bushings. The 150-kv. oil switches, however, still have their original compound-filled bushings.

There continues to be trouble in preventing the oil from leaking out of the oil-filled bushings in spite of assurances from the factory that the problem has been satisfactorily solved. This is not serious but somewhat annoying. The same trouble is encountered in keeping all joints tight in the conservator type transformers.

There seems to have been some real progress made in the method of packing large bushings for shipment. Two or three years ago it seemed almost impossible to get a shipment of 150-kv. or 220-kv. bushings from the eastern factories without a very high percentage of breakage. For the 220-kv. equipment delivered this year, approximately 260 bushings for 220-kv. and 150-kv. were received, all in perfect condition. It is to be hoped that this is really an advance in the art of packing and not merely a piece of good luck. One manufacturer crated these bushings in a vertical position with four or six in a crate. The bushings were well braced and completely housed. The other manufacturer crated each bushing separately with the bushing riding in a horizontal position, but it was rigidly supported at five points along its length.

Lightning Arresters

It has been the general policy of this company to install lightning arresters at all its stations on all voltages from 11-kv. to 150-kv., inclusive. Electrolytic arresters have been used almost exclusively until the last year or two. These arresters have been installed in various ways, sometimes on each line connecting to the station and sometimes on the station busses only; sometimes with reasonably straight connections and sometimes with very tortuous connections between the lines and the arresters, sometimes inside, sometimes on the roof, and sometimes on the ground outside of the building. The experience with all this variety of installations has shown that certain things should not be done.

1. Electrolytic arresters should not be installed inside of a building because of the fire hazard. Several bad fires have been caused by burning oil being thrown from arrester tanks at times of heavy discharges.

2. That electrolytic arresters should not be installed on a roof of a building because of the fire hazard and also because of the deteriorating effect of oil on a composition roof.

It is generally believed that the connections from the line to the lightning arresters should be as straight as possible. However, there are a very few cases reported in which the lightning did not follow the conductors provided for it, but instead, jumped to ground from the end of the bus, or from some sharp angle in the conductors.

As to the actual value of lightning arresters for the protection of station equipment from excess voltage due to lightning or to surges in the lines, it is hard to judge for two principal reasons; first, there is no adequate device available to record the discharges which pass through an arrester and, second, there are so few cases of lightning.

From the observations of station operators it is known that discharges occur when there is no lightning storm; but it is not known how many such discharges occur, nor whether any damage would be done if the arresters were not there to let the discharge pass to ground. Nor in the case of a lightning storm is it possible for an operator to observe and record more than a small per cent of the discharges that probably occur. There is a great need for a discharge recorder, which will give a reliable record of the time, and if possible the magnitude, of each discharge through an arrester and which will be sufficiently simple and inexpensive so that it can be installed on a large number of arresters. Such records, taken over a few years, would go a long way toward settling the controversy as to whether lightning arresters justify their expense.

It is quite generally conceded throughout the company that lightning arresters are a really worth while protection on circuits of 15-kv. and lower, particularly in cases of higher voltage lines coming in contact with lower voltage lines. There have been several such instances in which the arresters performed their functions properly and were not injured in doing so. The arresters are sometimes damaged by the higher voltage power currents as they are occasionally by the power current which follows a discharge due to lightning.

On the 60-kv. system the case in favor of lightning arresters is not quite so clear as it is on the lower voltages. The stations having transformers are almost universally equipped with them. Here again the

inadequacy of records makes it almost impossible to say whether arresters are or are not worth the money invested in them. The fact that they are installed shows where the predominant opinion lies.

The 150-kv. system was completely equipped with electrolytic arresters until about a year ago, with the exception of a considerable period some years ago when the arresters at Big Creek No. 2 were out of commission. Since about a year ago the arresters have been taken off the lines as the 220-kv. construction work made that necessary, and the fire at Eagle Rock eliminated those at that station. The fire brought forth the decision to permanently abandon the use of lightning arresters on the 150-kv. stations at Big Creek No. 1, No. 2 and at Eagle Rock, where the arrester tanks were inside the buildings. It had previously been the intention to leave these arresters in service, although the lines had been changed to 220-kv. It has not definitely been decided whether or not the outdoor arresters at Vestal will be re-installed.

On the 150-kv. lines there have been only two or three cases of trouble due to lightning, one of these was at Eagle Rock after the 150-kv. arresters had been removed. A 150-kv. insulator inside the building flashed over during a storm which was causing trouble on the 60-kv. and 15-kv. lines out of the same station. Another case of trouble attributed to lightning occurred on the 150-kv. bus connection inside the building at Big Creek No. 1, when the arresters were connected to the lines and apparently in perfect working conditions. At Big Creek No. 2, it was reported that the arresters discharged heavily at a time when lightning struck so near that the operators thought the building had been struck.

The arresters on the 150-kv. lines always discharged when 150-kv. line switching was being done. The statement is often made that arresters are not needed on 150-kv. and 220-kv. lines as a protection against lightning, but what will these voltage surges, which cause the lightning arresters to discharges during switching, do if the arresters are not there? The answer is, even though these voltages are high enough to jump the arrester gaps, they are not high enough to damage the station equipment. The fact that Big Creek No. 2 operated for many months without arresters indicates this. And some recent studies made with a surge recorder on the 150-kv. lines indicate that switching of a 100-mile section of line does not produce surges of more than 200 per cent normal voltage. These studies were made at Eagle Rock while the 150-kv. arresters were in service, however.

At Vestal, near the middle of the 150-kv. line, there were two cases of 150-kv. transformer insulation breakdown. The transformers were old and the insulation was admittedly of a quality inferior to that used in modern transformers. Yet the extreme thickness of insulation punctured made it difficult to believe that inferior insulation could be the cause of the failure. Perhaps high voltage did it, but the 150-kv. lightning arresters were in service, having very advantageous connections to the 150-kv. lines.

On the 220-kv. lines there are no lightning arresters and there probably never will be.

In regard to the types of arresters used by this company, the electrolytic arresters, which, until the last two or three years, have been considered the only arresters at all adequate for station service, have several faults, one of which is that they require expert maintenance, which often they do not get. Another fault is the fire hazard.

The oxide film arrester has become popular and this company is installing many of them on voltages of 60-kv. and lower. Thus far they have given no trouble and it is assumed that they will give at least as good protection as the electrolytic arresters. There is apparently no fire danger from them and this is greatly to their advantage. The maintenance promises to be very low. There has been one case of a discharge throwing some of the active material out of a stack of the disks. Examination showed that there had been many discharges through this stack. This discharge occurred at the time of a heavy short circuit on the system and the arrester was located in the heart of the system.

There is only one installation of the autovalve arresters of the distribution type on the system. This is on a 15-kv. line on Mt. Wilson at an elevation of 5000-ft., and though it is not definitely known to have functioned, at least one lightning storm has occurred on that part of the system since its installation.

The graded resistance type of lightning arresters have been installed on 11-kv. lines at several stations during the last two years. These have given no trouble to date and have functioned satisfactorily in several instances.

There is one installation of the Water Column Surge Arrester on the system. It functions properly when an arc is formed intentionally across the horn gap, but that is all that is known of it as yet.

TRANSMISSION OF ELECTRIC POWER FROM NORWAY TO DENMARK

The Danish, Norwegian, and Swedish Power Transmission Commission at a meeting held in Christiania in August, 1921, appointed an electrotechnical committee to investigate the question of transmitting electric power from Norway to Denmark. The report of this committee as to the possibility of power transmission and its probable cost, based on a number of thorough technical and economic investigations, has now been published. Four alternatives have been found. These are: A direct-current plant, either with cables under the Skagerak, or with overhead lines through Sweden; or an alternating-current plant with overhead lines through Sweden and with either aerial lines over, or submarine cables under, the Sound. (Minister J. D. Prince, Copenhagen.)

Methods of Voltage Control of Long High-Voltage Lines by the Use of Synchronous Condenser

BY JOHN A. KOONTZ, Jr.

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Review of the Subject.—*The following points are covered in this paper:*

Inherent characteristics of high-voltage lines and high-voltage transformers.

Effect of low power factor load on high-voltage lines as to limiting capacity and uses of condenser for increasing line output and obtaining good voltage control.

Characteristics which must be met by generators, condensers and regulating equipment in order to control properly voltage over all operating conditions.

THE long high-voltage transmission line is inherently very poor as regards voltage regulation. The inductive reactance is high, due to the wide spacing of wires required for the high voltage, or to the long spans that are necessary to reduce the cost of structures and insulation. Transformers must always be considered with the line when voltage regulation is concerned, and they must be designed with high reactance for the large power systems so that they can withstand the short-circuit stresses without mechanical damage, and reduce the short-circuit current to a value to give them sufficient heat storage that they will not be destroyed during system trouble. The wire must have a large diameter to avoid corona loss, but in general, this conducting material of the large cables is utilized to advantage in keeping the energy loss at a low figure. These cables, however, subjected to a high voltage, cause heavy charging currents to flow.

With these points in mind, namely, a system of high reactance, which at no-load carries a heavy charging or leading current, it is readily seen that the voltage generated by the flow of this current through the inductive reactance is added to the impressed voltage and thus the receiver voltage on the long transmission line is higher at no-load than the generator voltage.

The amount of this rise in receiver voltage at no-load will naturally depend on the design of the line and connected transformers, but with present 100-kv. systems this value may be as much as 8 per cent above the generator voltage, and the highest voltage lines met with may have an increase in voltage of almost double this amount under no-load conditions.

The load met with in practise is almost universally of a lagging nature. When this load with its lagging current is carried by the transmission line, we meet with the reverse conditions to that of an empty line with charging current, as the e. m. f. generated in this high reactance system when carrying lagging current, opposes the generator voltage, and the drop between generator and receiver ends of the line becomes quite excessive at low power factor and heavy load.

To show this effect of power factor on transformers and line capacities, figures from an actual curve will probably best serve the purpose. These results cover conditions as obtained on 190 miles of 160-kv., three-phase circuit. When maintaining the same generator voltage and a constant receiver voltage, we could transmit over such a line:

At unity	power factor	 60,000	kw.	
At 90 per cent	" "	 35,000	"	(current lagging)
At 80 per cent	" "	 28,000	"	" "
At 70 per cent	" "	 21,000	"	" "

From these figures it is seen that by change of power factor we can readily control the voltage to suit load conditions, and this is the method used on long lines, for in the first place it is an economic necessity to provide ample synchronous condenser equipment in order that the lines and transformer equipment may operate at near unity power factor, and it is a simple matter and of relatively small expense to provide the necessary regulator equipment in order that the voltage on the receiver system may be held constant and the power factor shifted to suit load conditions. The ordinary regulator of the Tirrill type is well suited for such work if the equipment is of the so-called broad range type such that it will control the field current of synchronous condenser or generator from practically zero to a value well above normal.

In some transmission systems where the ohmic resistance is low and the reactance high, it is possible to operate with equal and constant voltage at both ends of the line, but in most cases it is necessary to operate with the generator voltage higher than the receiver. The amount naturally depends on the size and length of line. In general this generator voltage should exceed the receiver voltage by at least the resistance drop of the load current in the connecting lines, and sometimes more than this value, depending on the power factor of the load that must be handled over the line.

In order to reduce the line losses, particularly at light load, line drop compensators can be used on the generator voltage regulators to advantage, as by proper setting of these power house regulators, they will increase the generator voltage as the load increases to take care of the line drop, and at light-load or

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no-load the voltage will be automatically lowered so that the receiver condensers will not be called upon to supply such large amounts of lagging line current at light loads. These line drop compensators will not only increase light-load losses but will also permit of use, in general, of condensers which are of slightly less cost, as a condenser will probably only have to supply one half or less of its rating in lagging line current at no-load conditions.

In order that satisfactory voltage control may be had in connection with any high-voltage lines, the apparatus must be specially designed to suit conditions.

The generator design must be such that the units will carry charging current without becoming self-exciting, or such that under all operating conditions, these units will require positive field excitation to give their normal voltage at normal frequency. When practicable, these generators should be of such size and so designed that one unit will charge a transmission line. This will not always be possible in connection with the extremely high-voltage lines, but where a single unit cannot be used, the station, or certain groups of machines in the station, should be designed to take care of line charging and testing, so that this may be handled with dispatch. One disadvantage in using more than a single machine for testing purposes is that when these units are operating at very low values of field current they have low synchronizing torque, and it is sometimes difficult to keep a number of units in step.

The synchronous condenser should be selected so that they will furnish their maximum kv-a. of lagging line current with field excitation above the residual voltage of their exciters. Condensers that are operated from the secondaries of transformers or tertiary windings of auto-transformers where power is not supplied from the same winding or from the condenser bus, should be carefully selected for operation with their respective transformer designs, so that the voltage variation obtained, due to power factor changes through the transformers, will not effect the condenser output, as it must be borne in mind that the condenser will have to furnish its highest voltage at a time when it is operating with its heaviest field current, or when furnishing leading line current, while on the other hand, when furnishing lagging line current and extremely low fields, the condenser will in turn be operating at well below normal voltage, which may effect the kv-a. output of the machine or reduce the field excitation to such value that it is difficult or impossible to obtain stable regulator operation. This variation in voltage in modern transformer design, may easily amount to 15 per cent.

Automatic voltage regulators are difficult to adjust to control the voltage of long lines under no-load conditions and obtain stable operation. This is due to the extremely low values of exciter voltage required on the generator and condenser fields and to the fact that quite a portion of the excitation is supplied by the leading current of the line, and the regulator is hence only controlling a portion of the total excitation.

This condition can be greatly improved by installing proper relays so that at suitable exciter voltage the condenser field rheostats and generator field rheostats are gradually cut into the circuit before this low-exciter voltage is reached. This resistance acts as a governor, tends to reduce surging and permits the exciter to operate at a higher voltage.

To obtain the low-exciter voltages necessary it requires very high resistance in the exciter fields over which the regulator contacts must operate if speed is obtained under no-load or line charging conditions. When using this large amount of resistance, very sluggish and poor regulator operation is obtained under heavy load conditions, so at load conditions it is necessary to shift the amount of resistance in the exciter field and make sure that all resistance is cut out of the generator and condenser fields. This can be taken care of by utilizing a proper type relay such that it will not only cut in the resistance on light load conditions, but will cut out this resistance in generator and condenser fields when the load increases to the proper value, an additional relay should be used connecting a resistance in shunt with the exciter field rheostat under heavy load conditions. Thus, by suitable adjustment of this relay, it can be made to cut in or out of the exciter field at suitable values in order to obtain the most stable operating conditions.

Voltage regulation of long lines is thus taken care of mainly by power factor control. The synchronous condenser not only serves to correct the power factor and in many cases reduce line losses, but it also gives a steadying effect on the system, which is difficult or impossible to obtain by any other method of voltage control. Short lines can be operated without condenser equipment, but it is difficult to obtain good voltage regulation by generator regulators alone when the load power factor is poor. For satisfactory operation of long lines it is essential that automatic voltage regulators be used at both generating stations and on the condensers at the receiving stations, and in general line drop compensators can be used to advantage in connection with the generator regulators.

TRANSOCEAN RADIO TELEGRAPHY

Commercial radio telegraph duplex circuits are now in continuous operation between New York and Commercial centers in England, France, Germany, Italy, Norway, Poland and Holland and by way of these stations to all countries in Europe, Africa and the Near East. Through American land line connections all places in the United States and Canada are in radio telegraph contact with Japan and Hawaii through the American high power radio station at San Francisco.

Test Results on the Performance of Suspension Insulators in Service

BY C. F. BENHAM

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***Review of the Subject.**—Megger test results on suspension insulators on the lines of the Great Western Power Company covering records since 1908 giving the percentage of depreciation by districts, viz., mountain, valley and coast conditions; also results covering the different types.*

* * * * *

THE suspension insulator has been the subject of much discussion, particularly during the last decade, when the faults of most of the products of earlier manufacture were brought to light and the great increase in their use, due to the general tendency toward higher voltages, considerably extended the interest in their behavior.

Extensive investigation has been carried on as to the cause of their deterioration, which was so pronounced in the older units and from which the later output is not entirely free. Many valuable data have been collected, from observation of insulators in actual service,—and experimentally as well,—and many conclusions have been drawn. At the present time the most generally accepted theories attribute failure to improperly fired porcelain,—either porous from underfiring or brittle from overfiring,—and even more to the mechanical stresses set up by the unequal expansion of the various elements of the usual cap and pin type of unit.

Most of the manufacturers have profited from the light which has been thrown on the subject; by a combination of better porcelain through more scientific mixing and heat control of the firing and the elimination of a large part of the temperature stresses through better design and methods of assembly, they have produced an insulator which is fairly long lived, as compared to the article supplied fifteen years ago.

Records are available covering the performance of a fairly large number of suspension units in use in the high-tension lines of one company,—a majority of which have been in service for about fifteen years,—and most of the balance from eight to twelve years.

After about six years of operation, the frequency of insulator failures was increasing at an alarming rate, and interruptions to service became so numerous that it was necessary to adopt a system of field testing to eliminate the faulty units.

From the indications of the first testing it was deemed advisable to replace one type of insulator completely—as well as the defective units of all types—using a new insulator of improved design and material. Subsequently other types were replaced as a whole and all insulators in certain sections where the rapid depreciation coupled with the inaccessibility made testing very costly. As a result failures have been reduced to only one or two sporadic cases in a year, at the most, with one period of twenty months in which none occurred at all. Testing intervals have also been increased to a fairly reasonable period, varying from one year in a few sections to from two to three years for the majority. This is governed partly by the type of insulator preponderating, but more especially by the climatic conditions prevailing, which vary considerably over the entire system.

Periodic testing has been carried on for the past nine years, and an analysis of the test records, with reference to the effect of different climatic conditions and also comparing the behavior of various types, is presented graphically in Figs. 1 and 2.

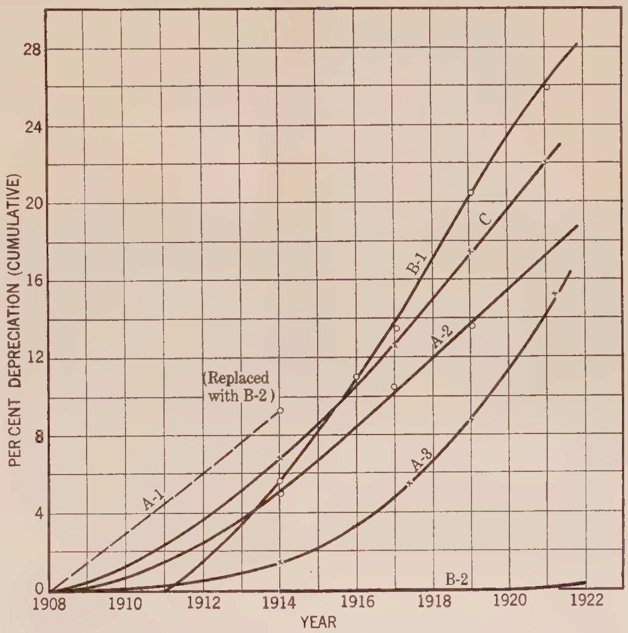

FIG. 1—DETERIORATION OF SUSPENSION INSULATORS UNDER DIFFERENT CLIMATIC CONDITIONS

Fig. 1 brings out the decided effect of temperature changes on the life of an insulator, and is rather conclusive proof that expansion stresses are a more serious problem than porosity. The four geographic divisions selected are quite sharply defined with distinct characteristics as to climate; while they vary greatly in extent, each is large enough to include a representative number of each of the various insulators and hence affords a fair comparison. The mountain and coast hill sections are subject to almost daily ranges of tem-

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perature of considerable magnitude, while in the upper and lower valley sections the only variations of any consequence are seasonal, though the daily range in the lower valley is perhaps a trifle greater on account of the winds. Again, the mountain and upper valley districts are comparatively dry, while the lower valley and coast sections are quite humid, the one being in a river delta and the other subject to fogs. Thus we have four distinct combinations of temperature cycles and humidity.

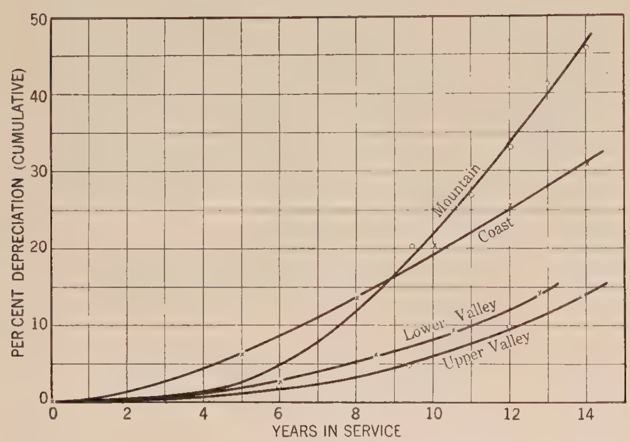
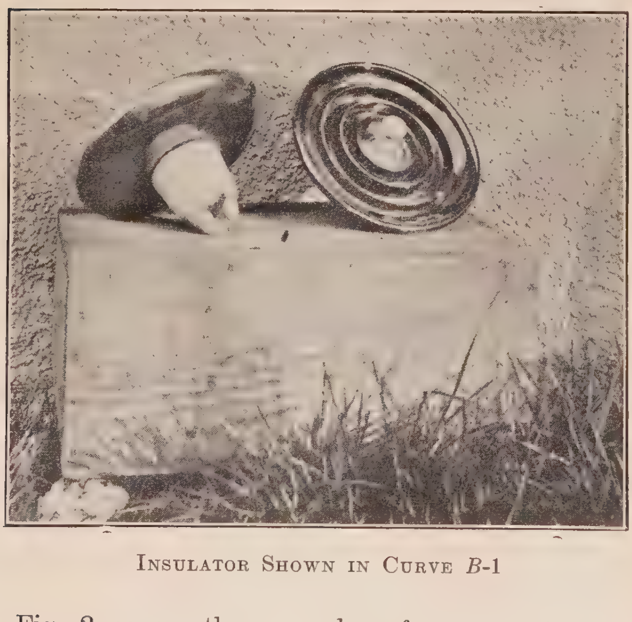


Fig. 2—Deterioration of Suspension Insulators, Comparison of Different Types

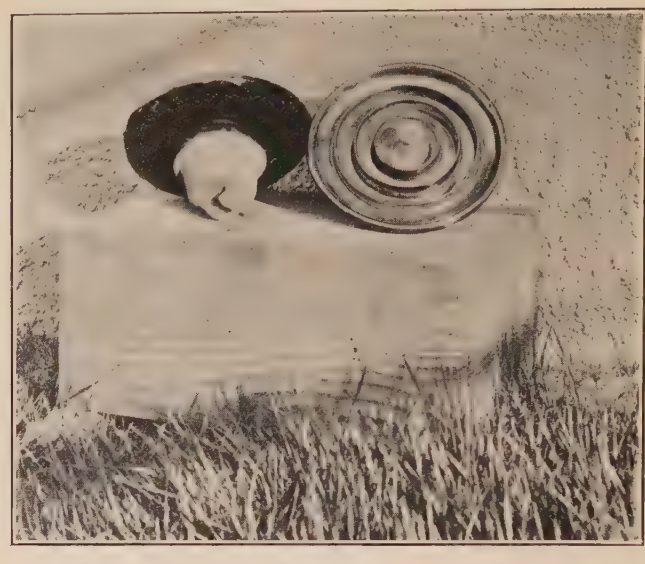
Curves designated by same letter are products of same manufacturer.



Insulator Shown in Curve B-1

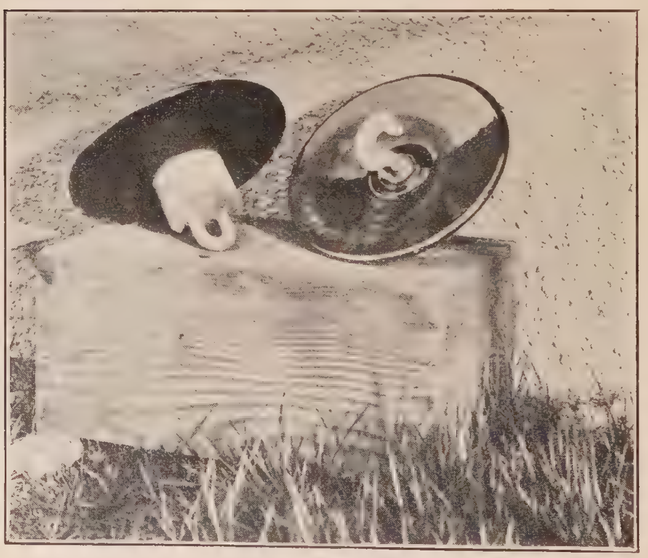
Fig. 2 covers the general performance of several different types of insulator, and is particularly interesting in the manner in which it brings out a comparison between different designs and stages of development of the same manufacture. The slight tendency of Curve B-1 to show a decrease in the deterioration can be accounted for in the fact that it includes insulators of two different ages. It has not been possible to segregate them generally in the test records, as they are alike in appearance, but a few specific cases indicate that the newer insulator has a much greater life due to improvements in porcelain and details of assembly. The proportion of older insulators is gradually being reduced through replacement, with a resulting decrease in the rate of depreciation of the combined group.

The most striking feature is the very slight de-



Insulator Represented by Curve B-2

terioration of the insulator shown in Curve B-2, which represents a fairly recent output of a design which is standard at the present time. Actual figures are perhaps more conclusive. Of some 10,000 units subjected to test, no failures developed in six years,



Insulator Shown in Curve A-3

and only nine in the seventh year and 10 in the eighth year or a total of only 19 units out of 10,000 after eight years of service. This would rather indicate that the insulator question is no longer a very serious problem, at least under the conditions which prevail among those in the foregoing study.

Transformers for High-Voltage Systems

BY A. W. COPLEY
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Review of the Subject.—*The designs of transformers for 220-kv. systems do not represent radical departures from designs which have become standard for lower voltages. The solidly grounded neutral system is used and advantage is taken of this to use graded insulation and reduced voltage test. Auto-transformers are used to connect between the 220-kv. system and existing high voltages and are connected star-star with delta tertiary. The tertiary may or may not be used to supply synchronous condensers but it is not used for the supply of power load.*

* * * * *

WHEN considering the use of extra high voltages for the transmission of electrical energy, the apparatus that first claimed the attention of the engineers consisted of transformers, switches and line insulators. Other apparatus, such as generators and synchronous condensers, have generally been considered as being unaffected or only slightly affected in their design because of their application in connection with high-voltage transmission. The problem of transformer design for 220,000-volt operation has been met and solved, however, without the encountering of any unforeseen difficulties or complications.

The application of transformers to 220,000-volt service has brought about a change in the generally prevailing ideas in regard to transformer construction in that the considerable savings obtained by the use of graded insulation on the 220,000-volt transformers has centered attention on similar savings which could be accomplished on transformers for the more moderate voltages. Except for this point, design problems on the 220,000-volt transformers have not been appreciably different from those which had been previously met in standard high-voltage transformers and design. The same types of design have been used, transformers of both the shell and core forms having been built and are now in operation on 220,000-volt circuits. The quality of insulating materials and the insulating oil have not been affected by the advent of the high-voltage. The same types of terminal bushings and the same principles of design have been followed.

It was universally recognized among engineers that a solidly grounded neutral should be used on the 220,000-volt system. This point being established, it became desirable to take advantage of the savings that could be effected in transformer manufacture by using only one high-voltage terminal and by grading the insulation from the maximum at the line end to a minimum at the neutral end of the high-voltage winding. Such grading of the insulation does not, however, affect the providing of extra insulation between turns or the turns immediately adjacent to the ends of the winding, and such extra insulation has been provided, both at the line end and at the ground end. This practise has been followed in recognition of the fact that surges or steep wave front potentials might be experienced at either end of the winding even when one end is connected solidly to ground.

In carrying out the design of the transformer for use on a system on which the neutral is solidly and permanently grounded, it has seemed to be possible and desirable to recognize the lower electrical stresses to which a transformer so applied would be subjected when compared with a transformer applied on a system in which the neutral is not necessarily permanently grounded. It should, therefore, be possible to reduce the insulation test to which the transformer is subjected.

It is evident that it would be impracticable to apply the voltage test specified in the Institute Rules between the whole winding and ground because of the grading of the insulation. The logical method of applying the insulation test is to ground the neutral end of the winding on the transformer core and to induce the test voltage in the winding. This gives the maximum voltage test at the line end and graduates it to zero at the neutral end. The dielectric test for a transformer as specified by the Institute Rules is two times the line-to-line voltage plus 1000 volts. The maximum operating voltage which might obtain on a transformer used on a line without solid grounding of the neutral would occur when one line became grounded and would, therefore, amount to the line-to-line potential.

The voltage test specified by the Institute gives a factor of safety of two on this voltage or, in other words, gives a margin equal to line-to-line voltage above the maximum normal obtainable voltage. When a transformer is used on a solidly grounded neutral system and is provided with graded insulation, the practise has been followed of testing with this same margin but as the maximum normally obtainable voltage in such a case is only the line-to-neutral value, the test given is the line-to-neutral value plus the line-to-line value or 2.73 times the line-to-neutral voltage.

As has been suggested, the attention brought to the graded-insulation, single-terminal transformer, by its

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use on 220,000-volt circuits, has brought about similar arrangements for more moderate voltages and recently transformers for 165,000-volt systems and also for lower voltages have been constructed on this principle. The savings accomplished are larger and more important on the very high-voltage transformers, but there is also a very real saving on transformers built for lower voltage operation.

On the transmission systems now arranged for 220,000-volt operation, special conditions have called for the use of auto-transformers connected to the high-voltage line. The Southern California Edison Company had been operating their Big Creek lines at 150,000 volts and the two original Big Creek plants and the Eagle Rock step-down substation were provided with transformers and switching equipment to give or to utilize this potential. It was considered economy, therefore, to allow this 150,000-volt apparatus to stand and to obtain the 220,000-volt potential by auto-transformation. This necessitated star-star connection between the two voltages and the use of tertiary windings to supply the third harmonic component of magnetizing current and to provide a comparatively low impedance path for the flow of the unbalanced current demanded in the case of a ground on the star-connected system. The importance of maintaining this tertiary winding in service under all exigencies was considered by the engineers of the Southern California Edison Company to be enough to warrant the exclusion from this winding of any other load such as low-voltage local distribution or synchronous condenser current.

The newer Big Creek power plants and the new Laguna Bell substation, near Los Angeles, are equipped with two-coil transformers connected in star on the high-voltage, and delta on the low-voltage side as no intermediate 150,000-volt potential is required.

The Pacific Gas & Electric Company have had a 100,000-volt system in use in the San Francisco district for many years and it was planned to bring the power from Pit River into the district and to transmit it to the 100,000-volt system already in existence. Thus transformation from 220,000 volts to 100,000 volts became necessary and auto-transformers provide the most economical means of making such transformation. These auto-transformers are located at the Vaca substation. They are connected star-star and provided with a delta tertiary winding which cares for the third harmonic component of magnetizing current, unbalanced ground current in case of line faults, and at the same time supplies the synchronous condensers used for line regulation.

It is not practicable to use the tertiary winding for supplying local distribution and at the same time synchronous condenser current if the field of the synchronous machine is varied in such a manner as to give a constant potential on the high-voltage side of the transformer. This prohibition is on account of the voltage variation which must obtain on the tertiary winding under this condition.

REGULATIONS FOR RADIO ANTENNAS

It is intended to include in the next edition of the National Electric Safety Code some regulations for the construction of outdoor radio antennas. A subcommittee to deal with this subject held its first meeting at the Bureau of Standards on October 19 under the chairmanship of L. E. Whittemore of the Department of Commerce.

The Committee outlined proposals for the regulation of antenna construction and after further consideration these will be reported to the large Sectional Committee which is carrying out this revision of the Electrical Safety rules according to the procedure of the American Engineering Standards Committee.

TESTS OF RADIO RECEIVING SETS

The results of tests on radio receiving sets made by the Bureau of Standards are given in a series of letter circulars now being issued. The first of this series is Letter Circular No. 90, which gives results of tests on certain electron tube receiving sets. The second, Letter Circular No. 93, describes the results of tests on receiving sets using crystal detectors. The third paper of the series, Letter Circular No. 102, has just been issued and describes results of tests on a number of short-wave regenerative receiving sets. It is believed that the methods followed and the examples given in these reports will be of assistance to manufacturers in the development of methods of testing and describing and improving their products.

These letter circulars have been issued in mimeographed form, but a limited number of copies are available for distribution to testing laboratories, manufacturers, and others who can show that they are directly concerned with the testing of receiving sets. Requests should be addressed to the Bureau of Standards.

SOURCES OF RADIO INFORMATION

A considerable number of inquiries received at the radio laboratory of the Bureau of Standards call for similar elementary information regarding radio publications, radio laws and regulations, station and operator's licenses, and call books. In order to facilitate the handling of these inquiries, Circular No. 122 was prepared and recently revised. The new edition gives the more important radio periodicals, lists the important Government radio publications, and the radio books of general interest issued by various publishers, gives a brief summary statement regarding the radio laws and regulations of the United States and Canada, and gives a map showing the radio inspection districts. A copy of the second edition of Bureau of Standards Circular No. 122 may be purchased for 5 cents from the Superintendent of Documents, Government Printing Office.

Waterwheel Construction and Governing

BY E. M. BREED

Pelton Water Wheel Co., San Francisco, Cal.

THE design and manufacture of hydraulic turbine equipment has been very considerably accelerated within the past few years; more particularly since the World War, as the lessons it taught us in regard to diminishing fuel sources and the interruption to fuel supply through labor disturbances, both directly in fuel production and indirectly in its transportation, have stimulated in a very decided manner the investigation and development of the water powers of the nation. The remarkable strides made in the long-distance, high-tension transmission of power have rendered economically available water power sources formerly considered impossible and, particularly, in the West where long distance power transmission and super power zones have now become realities.

This very considerable increase in the actual and prospective use of hydraulic prime movers has resulted in the past few years in pronounced activity in study and experimentation, to improve the design features of existing types of hydraulic turbines and in the development of new types. This progress is evidenced, not only in the turbines themselves but in their auxiliary equipment, as well as in the water conduits above and below the turbine proper. The rather gratifying results of this investigation and study have introduced a new period in turbine design, characterized by a desire to design the hydraulic equipment to fit the physical conditions and load requirements existing, rather than an attempt to modify the physical conditions to suit certain recognized types of turbine design, based on accepted "type characteristics."

This present healthy condition in the field of turbine design, gives the hydraulic engineer a very considerable latitude in the choice of type and speed of turbine, and in the general arrangement of the hydraulic equipment. As a result, the collaboration of the turbine manufacturer and the power company engineers in the preliminary study of any certain development becomes more desirable than ever, thus emphasizing the community of interests between the manufacturer and the power company. This broadening of the field of possible types and designs of turbines, becomes apparent in three principal directions; a very considerable increase in speeds available for low and medium head turbines; a considerable extension of the maximum heads for which turbines can be designed, and an increase in the capacity of unit considered economically feasible.

The record, as far as size of unit is concerned, is set by the Niagara Falls Power Company which placed contracts last year for three single-runner vertical turbines each of 70,000 h. p. capacity. The engineering fraternity is inclined to expect such records to be set, from time to time, at Niagara Falls as conditions are such there as to warrant the installation of large units, but there have been a number of other installations throughout the country of large size turbine units, and the time seems to have passed when turbine units of less than 40,000 or 50,000 h. p. occasion any comment. It is not too much to say that should the economics warrant, the capacity of individual hydraulic turbine units will reach 100,000 h. p. in the not distant future.

Under conditions where the operating heads are moderate, that is to say 300 ft. or 350 ft., these large size units do not produce design requirements differing materially from those with which we are ordinarily familiar. There are, of course, vast differences in the physical sizes of component parts but, generally speaking, large turbine units under these moderate heads may be said to have been developed homologously from designs of lesser capacity. The 70,000-h. p. units referred to, will be of the same general design as the 55,000-h. p. units manufactured by the same company for the Queenston Plant of the Hydraulic Power Commission of Ontario, and as the 37,500-h. p. units manufactured for Station No. 3 of the Niagara Falls Power Co. They will operate at 107 rev. per min. under 213.5 ft. head. Some idea of the physical dimensions may be gained from the fact that the casing inlets will be 14 ft. in diameter; the power water being controlled by means of 21 ft. by 14 ft. Johnson needle-type valves. The over-all diameter of the cast steel spiral casing will be approximately 42 ft. and the outside diameter of the cast steel runner will be approximately 15 ft. 6 in.

In general, however, it may be said that size in a unit is not an advantage in itself, as seems to be sometimes considered. The increase in efficiency, if any, resulting from an increase in capacity beyond say, 30,000 h. p. to 35,000 h. p., is probably very small, and the decrease in cost per h. p. in most installations of extremely large size units is problematical when the increase cost of foundations, super-structure and auxiliary hydraulic equipment is considered. On the other hand, there are probably only a few power systems in the country where units of 50,000 h. p. or larger, can be used to advantage and a very careful study should certainly be made of the present and expected load requirements, stream flow conditions and expected shape of the efficiency curve below half load before large capacity units are decided upon. In many cases it will probably be found that large capacity units would be operating a considerable percentage of the time on a low part of the efficiency curve. This not

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only means inefficient use of the water resources, but also rapid deterioration and, consequently, high up-keep charges on the runner, wicket gates and adjacent parts, with frequent removal of the unit from service.

The next most important forward step in turbine construction as marking the progress of the art, is found in the development on the Pacific Coast of what may be termed high-head turbine design. Indeed, from the viewpoint of engineering significance, the high-head turbine should probably be named first as the large number of high-head power sites available in the Rocky Mountains and West, where some seventy per cent of the total undeveloped power of the nation exists, gives rise to the expectation that a considerable proportion of turbine development in the future will be of the high-head type. The development, at their Kern River No. 3 Plant, by the Southern California Edison Company pioneered the field of high-head turbine construction with an installation consisting of two, 25,000 h. p. vertical turbines operating under an effective head of 810 ft. Many problems not ordinarily met in low-head turbine design required solution. Since the plant has been successfully operating for some three years, it may be definitely said that the solution of the high-head turbine has been proved.

The Portland Railway Light & Power Company has at the present time under construction for its Oak Grove Plant a high-head reaction turbine of 35,000 h. p. capacity to operate at 514 rev. per min. under an effective head of 850 ft. This plant when put into operation will be the highest head turbine installation known, this distinction at the present time being held by the two turbines of the Southern California Edison Co., previously described.

While in the larger low-head installations lignum-vitae bearings, water-lubricated, are still extensively used, the trend is nevertheless toward babbitt-lined bearing, oil-lubricated, and in the high-head turbines these have been used exclusively. It will be obvious that in the high-head installations the clearance space between the runner and the stationary parts of the turbine casing must be kept at a minimum if the leakage and consequent errosion of the high-velocity water is to be properly controlled. It is customary, therefore, to keep the high-head turbine runners rigidly in their position of alinement and babbitt-lined bearings, in which the space allowed for the maintenance of the lubricating oil film is kept as small as possible, are essential. Coincident with the necessity for keeping the runner clearances at a minimum, is the requirement for some kind of runner seal which with such close clearances will not leak, seize, nor wear. These needs have been met by the company, with which the writer is connected, through the development of rubber seal rings and several units have been in successful operation for a couple of years under very difficult silt and sand conditions, using this type of seal ring.

A great deal of attention and study has been given to the problems arising in high head turbine design, due to the increased velocities in the water resulting from operation under these higher heads. The utmost care must be taken in the design of turbine casing, speed ring, guide vanes, etc., to prevent as far as possible, formation of eddies and disturbance of the stream line flow. The volute casing is so designed that the cross-sectional area of the volute passage will decrease when passing around the circumference of the turbine at a rate sufficient to provide a continually increasing velocity in the water, inversely proportional to the radial distance from the axis of rotation of the runner. This will deliver the power water to the guide vanes under the same velocity and pressure head at all points of the guide vane circle, and it is interesting to note that the use of the Overn disk-type guide vanes, as developed by one of the Eastern hydraulic manufacturers, tends to reduce hydraulic losses at this point to a negligible quantity through the thin stream line shape permitted by this design of vane.

With the increase in the size of turbine units, the problem of governing has undergone very considerable change. The greater capacities of single-turbine units have come about to a considerable extent, from the fact that they are being installed by companies which are operating large systems and which can, therefore, effectively absorb the output of these single high-powered units en bloc, with the normal load fluctuations of their systems being easily taken care of by other units or plants of smaller capacity tied into the same transmission net work. Therefore, from the viewpoint of regulation, the governing problem on the larger units is not severe. On the other hand, the importance of perfection in the governing mechanism in these larger units can very properly be considered by realizing the responsibility placed upon it and its power to do extreme damage if it fails to function properly. For instance, the length of governor stroke on a large turbine operating under moderate head may not be in excess of 9 in. to turn on the load from zero to maximum capacity. Obviously, the rate with which this vast amount of energy may be turned on or shut off must be absolutely under control. These considerations alone have led to studies in governor design that, without question, are producing a much higher type of construction than in the past. Facilities have been provided for changing from governor control of the turbine unit to hand control by the movement of a single lever. Governors are also usually equipped with devices for automatic emergency operation to close down the plant should almost any unusual condition develop, either electrically or mechanically. Complete switchboard or remote control in the matter of synchronizing, limiting or adjusting of load and emergency shut-down are now included in the modern governor.

It has become quite general practise to install individual oil-pressure sets for each governor and

turbine unit, as this gives an independence in operating control and also largely helps to keep the physical size of the pressure-oil units within such limits as will make them fit harmoniously into the power house plan. Advocates of the central oil-pressure systems usually cross-connect the individual oil pressure sets by means of suitable piping so that any one oil-pressure set may be used for any turbine. Where conditions permit, individual oil-pressure sets are made large enough not only to provide pressure oil for their own turbines but also to operate an adjacent turbine under emergency conditions.

Pressure regulators, or relief valves, have undergone considerable change of design by reason of the large water quantities that now must be handled and on occasion also because of the high heads under which they must discharge. Mechanically-operated relief valves which take their motion directly from the gate-shifting mechanism on the turbine are essential and the entire pressure regulator structure should be so designed as to safely withstand the full effort of the governor so that should an obstruction block the opening of the relief valve, the turbine guide vanes will be effectively prevented from any further closure, as otherwise a serious ram or rise of pressure in the pipe line would result. It is also essential that the pressure regulator shall have a discharge characteristic which will approach as closely as possible the discharge characteristic of the turbine guide vanes, as otherwise the inverse movement of the guide vanes and relief valve will cause variations of the velocity of flow in the pipe line which may result seriously.

Another development of importance in the turbine field is the rapidly increasing use of the so-called high-speed or propeller type runner. The Francis type runner, which has been the standard for many years, has been developed and perfected so that for low head work, specific speeds as high as 80 or 85, in the English system, can be gotten with fairly high efficiencies, but as these appear to be about the limit to be expected, a great deal of experimentation and study has been given to the development of a new high-speed type of runner. Some of the advantages gained by the use of the propeller type or diagonal runner are:

First. A reduction in the first cost of the hydro-electric unit, due to the smaller dimensions resulting from the higher speed, and a reduction in the cost of the super-structure of the power house, cranes, etc. owing to the lighter weight of the rotating element and other parts to be handled.

Second. The mechanical strength of the diagonal runner is improved over that of the Francis type as the overhang of the vanes is less and the connection between runner hub and vane considerably longer, resulting in smaller bending stresses in the vanes. As the vane is unshrouded the construction permits of the use of separate vanes which can be bolted to a central hub, allowing the replacing of a single vane, if accidentally damaged.

Third. The design of the diagonal runner is much simpler than that of an equivalent Francis runner, thus eliminating to a very considerable extent the possibility of erosion, cavitation, etc., and providing a more direct passage for the water. The runner usually consists of from four to eight vanes, in comparison with the Francis type, having from fourteen to eighteen vanes, so that the clear openings through the vanes are considerably greater, preventing to a very considerable extent, the possibility of clogging with foreign material.

A considerable number of these high-speed runner units have been installed in the past two or three years and very satisfactory results obtained. Numerous tests have been made both of the model runners and of complete units installed, and efficiencies of 88 per cent to 90 per cent can reasonably be expected from this type of runner when designed for specific speeds ranging from 110 to 150, English system; the efficiency dropping off somewhat as the upper range of specific speed is reached. Possibly the most notable installation thus far made with this type of runner, is that of the Manitoba Power Company, installed last year consisting of three 28,000 h. p. vertical hydroelectric units with propeller type turbines, designed to operate at 138.5 rev. per min. under a net effective head of 56 ft. This corresponds to a specific speed of 153, English system. The runners of these turbines contain six blades and have an over-all diameter of approximately 16 ft. These units have indicated very clearly the remarkable characteristics of this type of runner, in particular, its ability to operate at normal speed under greatly reduced heads, with a considerable power output, the range of effective head being from 28 ft. to 56 ft. It is interesting to note, in this connection, that the runner of the Manitoba Power Company turbines is within a few inches of the same diameter as the Francis type runner of the turbines installed at the Cedars Rapids Plant on the St. Lawrence River, which were manufactured by the same company eight years earlier, but that the specific speed of the Manitoba turbines is practically twice that of the Cedars Rapids units, notwithstanding the Cedars units represented the highest specific speed obtainable at that time.

The subject of draft tube design is one which has caused a great deal of discussion in recent years and on which there is a considerable diversity of opinion. Numerous tests have been conducted for the purpose of determining the relative values of the different types, but as most of these tests have been made with model runners and tubes where slight variations in construction and setting of the tubes produced widely differing results, there still exists a great difference of opinion as to the most efficient form.

Applications of Long Distance Telephony on the Pacific Coast

BY H. W. HITCHCOCK

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Review of the Subject.—*This paper deals with the general problem of providing long distance telephone service on the Pacific Coast. A description of the present toll plant is given and the applications which have been made of recent developments in telephone practise are illustrated. Reference is made to the extensive use which has been made of carrier telephone and telegraph systems, and the many special problems, such as the loading of long toll entrance cables, which these systems introduce, are pointed out. The service to Catalina Island is described to illustrate the changes which are taking place in the communication art. This service was first provided by means of a radio link to which a privacy system was later added. This radio system was later replaced by two submarine cables between the island and the mainland. The mechanical and electrical characteristics of these cables are given, together with a description of the work of laying, which was done principally by the government cable ship, "Dellwood."*

WITHIN the last few years the extensive and systematic research which has been carried on by the Bell Telephone System has resulted in developments in the art of long-distance telephony of facilities whereby the telephone service rendered the public has been greatly extended and improved. Many of these new developments have been ably described in Mr. Osborne's paper, and in others recently presented

FIG. 1

which are indeed remarkable and have placed at the disposal of the Bell companies an ever increasing variety before the Institute. It is the purpose of this paper to point out the extensive use which has been made of these newest facilities on the Pacific Coast and how the various elements have been combined under the par-

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ticular conditions encountered here to form a coherent toll plant.

To illustrate this, the accompanying map has been prepared. Backbone routes extend north from San Diego through Los Angeles, San Francisco, Portland and Seattle, to the international boundary where connection is made with the British Columbia Telephone Company's lines to Vancouver. Contact with the territory to the east is effected by leads to Phoenix, Salt Lake, Boise and Butte. The heavy lines on the map represent leads on which carrier systems are in operation. The medium weight lines represent other main leads not so equipped at present, while the light lines represent some of the more important branches. Toll cables are represented by the short heavy lines in the immediate vicinity of the larger cities. Future carrier facilities for which plans are actively under way are indicated by heavy dots on medium width lines. Various types of repeaters are also shown.

In any telephone connection regardless of its length the aim is to maintain a satisfactory equivalent or standard of efficiency. All direct circuits between the large cities and towns are designed to be well within this equivalent. Where no direct connection exists, two or more circuits joining intermediate points are connected together. When the equivalent of such a built up circuit exceeds the limit which has been set, repeaters are inserted at the intermediate points to preserve the necessary over-all efficiency.

To illustrate the manner in which the several types of circuits may be combined, let us assume a connection established between Avalon on Catalina Island and Deer Park, Washington, a tributary of Spokane. The circuit arrangement together with the comparative power level at all points when the Avalon party is speaking is shown in Fig. 2. Starting from the Avalon end we encounter in succession, a deep sea submarine cable, a long loaded toll cable, the 25-kilocycle channel of a carrier telephone system operating over No. 12 N. B. S. gage wire (173 pounds per wire mile), a trans-bay lead-covered submarine cable, the 10-kilocycle channel of a carrier system operating over No. $8\frac{1}{2}$ B. w. g. wire (435 pounds per wire mile), a No. 8 gage open-wire phantom and a No. 12 gage open-wire circuit. Two through line voice frequency repeaters and seven carrier-frequency repeaters are employed. Voice-frequency cord circuit repeaters are inserted at Los Angeles to connect a toll cable with a carrier system, at San Francisco to join two carrier channels, and at Portland to connect a carrier channel with an open-wire phantom circuit.

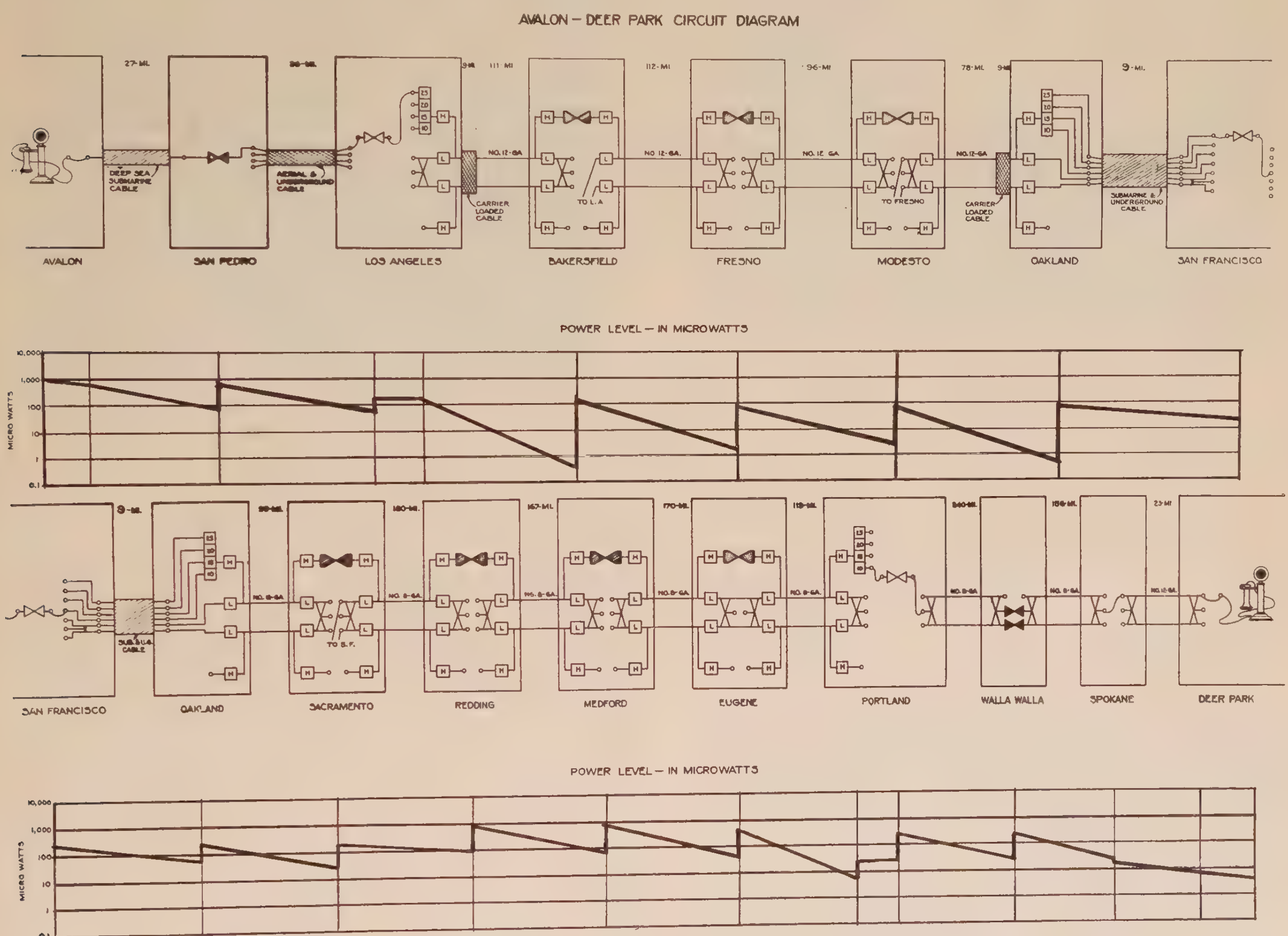

Fig. 2

In addition to the various types of circuits and am-

plifiers involved in this connection the power relations are also of interest. Consider for example the conditions at a time when the power delivered to the line in question by the Avalon telephone is 1000 microwatts. The over-all circuit efficiency is about 0.4 per cent (25 mile equivalent) so that four microwatts are delivered to the Deer Park instrument. Were the cord circuit repeaters omitted the power transmitted would be reduced to 0.02 microwatts. Should all the repeaters including those in the carrier systems be omitted, the received power would be 1.3×10^{-16} microwatts.

Not only is it necessary to maintain a certain overall efficiency, but also is it required that the power be kept within certain upper and lower limits at all points along the way. Should the voice currents become too great, overloading of the repeater tubes accompanied by distortion of the speech waves will occur. If the current becomes too weak, the circuit will be noisy or experience excessive crosstalk from other lines. These upper and lower limits make it necessary to amplify the current at regular and fairly frequent intervals as

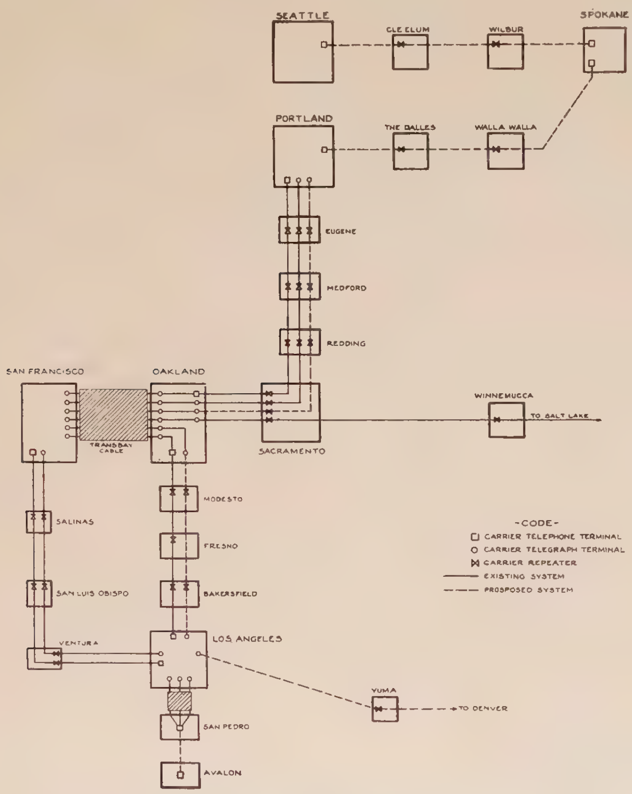

Fig. 3

is done in the circuit shown. Were all the amplification to be effected at the receiving end, the noise and crosstalk would completely drown out the speech current. In case the amplification were all applied at the sending end the speech input power would have to be about thirty billion kilowatts. Such a mode of operation is of course impossible.

One of the most noteworthy things about the Pacific Company's toll plant is the extensive use which has already been made of carrier systems. This is due largely to the fact that the great distances which separate the main centers of population are sufficient to justify the large cost of carrier terminal and intermediate repeater equipment, because of the resulting saving in line wires. Fig. 3 shows the systems now in use and those upon which work is progressing. At the present time, there are in operation 6400 channel miles (10,300 km.) of carrier telephone and 18,500 miles

Fig. 4—Terminal Equipment of Two Carrier Telephone Systems at Oakland

(29,800 km.) of carrier telegraph. These figures will soon be raised to 8600 miles (13,800 km.) and 32,300 miles (52,000 km.) respectively. All of the eight San Francisco-Los Angeles circuits now are carrier channels as are the four San Francisco-Portland circuits. It may be of interest to note that when the carrier systems now contemplated are completed it is expected that it will be possible to talk by carrier alone for practically the entire distance from Avalon to Spokane, which is more than sixteen hundred miles (2600 km.).

Among the special problems which the use of the new facilities presents is that of bringing the toll circuits into San Francisco. Those which enter from the north and east must cross the bay in submarine cables which are too long to be operated on a non-loaded basis. Fortunately, Goat Island provides an intermediate loading point between Oakland and San Francisco for the circuits from the east, although the minimum spacing which is obtained in this way is 12,000 feet (3660 meters), or more than twice the spacing which is used normally with cables associated with open wire. Special coils have been developed to meet this condition and are used on all the existing submarine toll entrance cables, since the provision of submarine loading coils would not have been as economical.

Although lines loaded in this special manner are satisfactory for voice frequency circuits, they cannot be used for carrier systems. It has therefore been

necessary to make Oakland the carrier terminal point for all such systems operating over wires which approach the bay from the east, although the individual channels, both telephone and telegraph, are extended across the bay to San Francisco and terminated there.

Another special problem incident to the use of carrier systems is the loading of long toll entrance cables. Two of these, each about nine miles (14.5 km.) in length, occur in this territory. One extends from the Los Angeles office north to Cahuenga Pass and provides entrance facilities for both the coast and valley leads. This cable will soon be extended to Simi junction, an increase of three miles (5 km.). The second cable

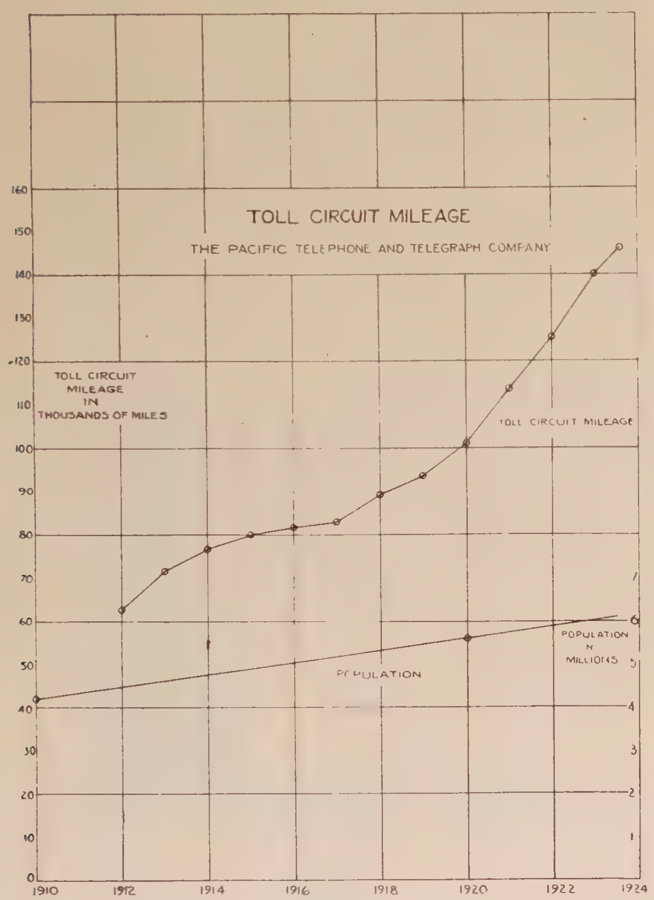

Fig. 5

extends from Oakland to San Leandro and serves the valley circuits to Los Angeles. Both of these cables have been loaded at frequent intervals with special coils so as to render them suitable for use with carrier systems. A third cable 12.5 miles (20 km.) in length extending south from Seattle will also be loaded for carrier operation in the near future. Such loading is quite expensive and has an important bearing on the question of carrier circuit economy.

One of the most difficult problems encountered in this territory is to anticipate and provide for the rapid increase in the long distance or toll business. The extent of this growth is shown on Fig. 5, which gives the total toll circuit mileage for the last ten years. For comparison the increase in population for this period is also shown. In order to care for this increase in business, extensions to the plant are constantly being made. Mention has already been made of the several carrier projects now under way. Toll cables are to be placed between Seattle and Tacoma, between San Francisco and San Jose and between Los Angeles and Long Beach to supplement those now in use. A cable

Fig. 6

is soon to connect Los Angeles with Anaheim and other Orange County points while another is now being designed for use between San Francisco and Sacramento.

New open-wire circuits are constantly being added to the plant. A group of No. 8 gage wires (435 pounds per wire mile) is being strung between San Francisco and Los Angeles by way of the coast. These wires are being specially transposed to facilitate carrier operation

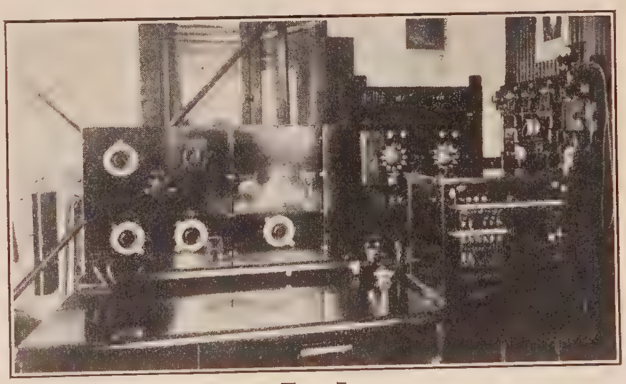

Fig. 7

and together with those already in place will provide facilities for several new carrier systems over this route. The new No. 8 gage circuits from Los Angeles to Denver will furnish a new and much needed outlet for eastern business and will also materially reduce the possibility of total interruption to service between the coast and eastern points.

No better illustration of the rapid advance in the

art of communication or the application of new methods to the telephone toll plant can be found than that provided in our territory by the service to Catalina Island.

In 1920 commercial telephone communication was established between Pebbly Beach on Catalina Island and Long Beach by means of a two-way radio system. At the two ends the connection was extended to Avalon and Los Angeles respectively by means of wire circuits. Soon after this a telegraph channel for handling commercial messages was added. This is the first and perhaps the only instance in which radio has been used as an integral part of a telephone toll system and operated under the same severe requirements as are imposed on the wire circuits.

From the time of its installation, this circuit handled a tremendous volume of business. That it was quite efficient is proved by the fact that it was used in frequent demonstrations such, for example, as the one in 1921 when a conversation was held by way of the transcontinental telephone line between Catalina and the S. S. Gloucester one hundred miles (160 km.) off the Atlantic coast; and again in the same year when Catalina talked to Havana by way of the radio and the newly completed Key West-Havana submarine telephone cable,—a total distance of about 5500 miles (8800 km.).

One objection to the radio circuit was the lack of secrecy, and the recent increase in the use of radio sets for the reception of broadcasting rendered this increasingly troublesome. In order to obviate this difficulty a privacy device which was recently developed by the Bell System was installed on this circuit. This privacy system although it in no way impaired the quality or volume of the speech over the radio circuit, rendered it unintelligible to anyone listening with a radio receiving set of the usual type.

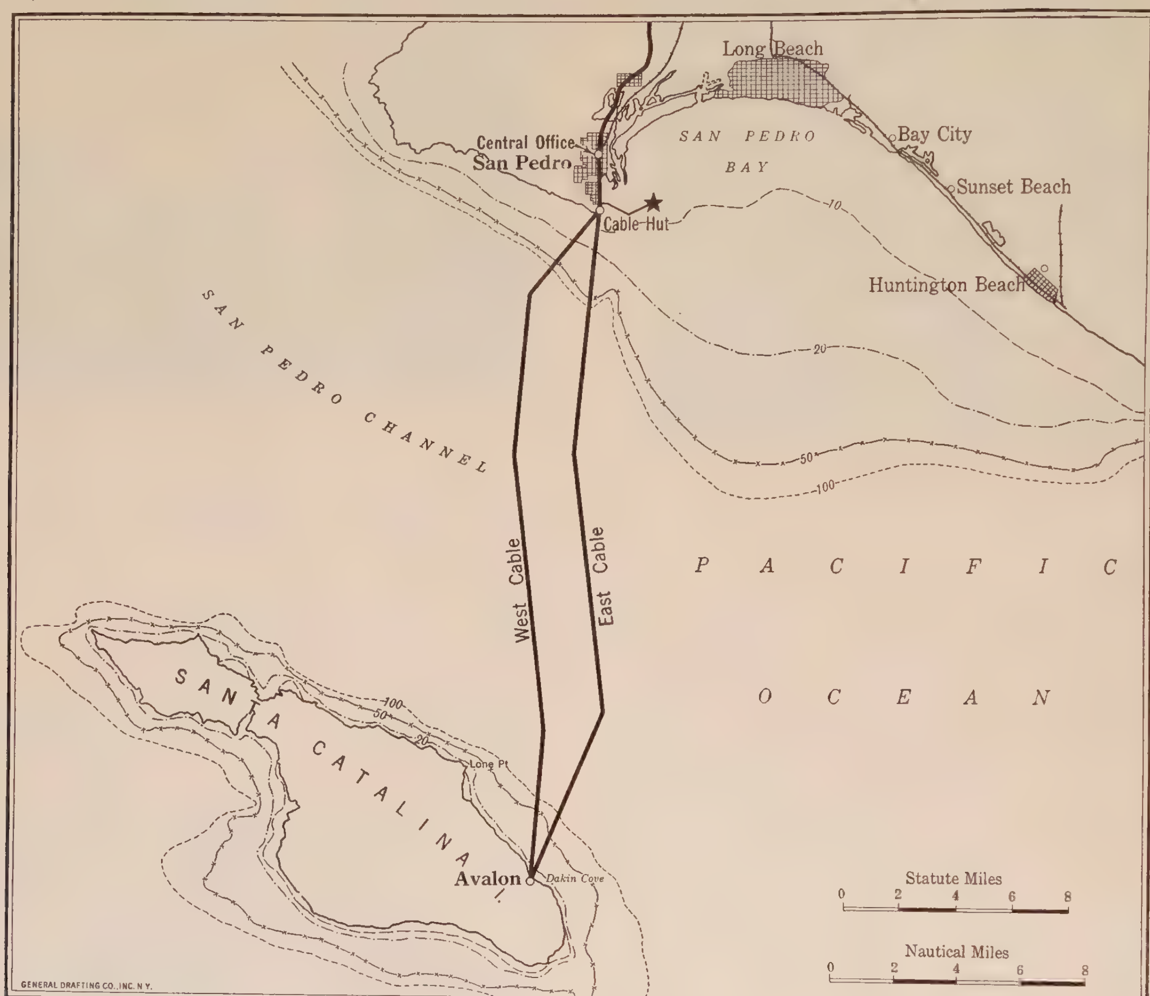

Fig. 8—Location of South Catalina Island Cable

The radio system recently was replaced by two deep sea cables between Avalon and the mainland. The license of the radio "talk bridge" expired on August 1st and the Department of Commerce requested that its operation be discontinued, making its wave lengths available for broadcasting.

The capacity of the ether for radio messages is distinctly limited and when such services as broadcasting, ship-to-shore telegraphy and telephony, radio

compasses, etc., which can be handled only by radio, have been accommodated, the available wave lengths of the ether are about exhausted. Consequently, the change from radio to cable in a case like Catalina Island, where the cable is not only feasible but more economical than radio, was for the good of the service, especially as the large volume of business which developed made it necessary to provide additional facilities.

The submarine cables were manufactured by the Western Electric Company at Hawthorne, Illinois, and in their design have been incorporated many of the most recent developments in submarine cable construction. The approximate position of these two cables is shown in Fig. 8. At the Avalon end they

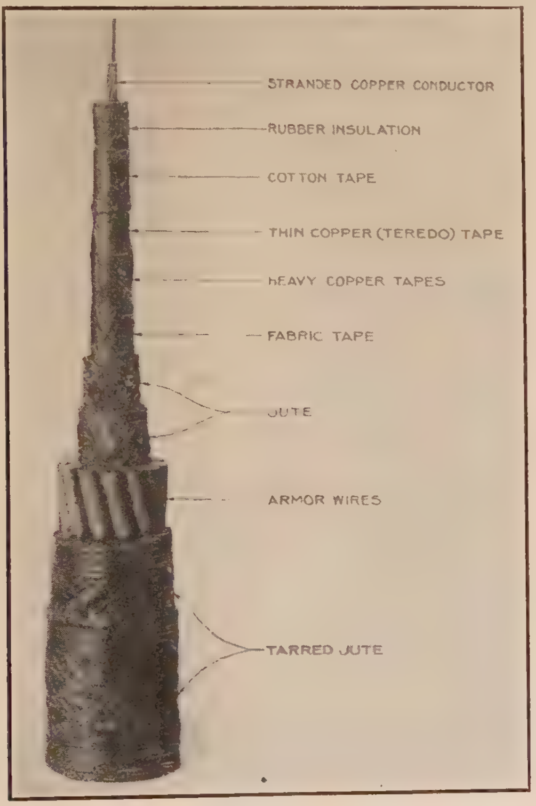

Fig. 9

terminate directly in the new central office located about 800 feet (240 meters) from the shore. At the San Pedro end a small concrete hut was erected at the base of the breakwater in which to terminate the cable and house the special terminal equipment. This was selected as a landing point as the water in the cove formed by the shore and the breakwater is comparatively quiet and at this point a small sandy beach has been formed. At all other points in the neighborhood of Point Fermin the shore is very rocky and steep and the water quite rough. The distance between Point Fermin and Avalon is about twenty-three nautical miles (6087 feet or 1856 meters per nautical mile). Near the center of the channel the water reaches a depth of slightly over 3000 feet (900 meters). For the greater part of the distance the cables were laid about two miles (3.2 km.) apart. This separation was maintained so as to give greater insurance against simultaneous interruption and to render it easier to pick up one cable without disturbing the other.

The cables themselves are of the deep sea type. Such a cable provides but a single physical circuit formed by the central insulated conductor as one side and the sea water, armor wires, and copper tapes, all in parallel, as the other side. The details of construction are shown in Fig. 9. In shallow water near

Fig. 10—Cable Barge at Avalon

the shore where there is danger of injury from anchors or abrasion due to tide and wave movement, large armor wires are employed. In deep water where these dangers are largely absent, the armor is formed of smaller wires having a high tensile strength. Such armoring provides a light and flexible yet strong cable, suitable for withstanding the severe strains encountered in laying or picking up the cable in deep water. For the cable lying in water having a depth of between 600 and 1800 feet, (180 and 550 meters) an intermediate

Fig. 11—U. S. Cable Ship "Dellwood"

type of armoring employing medium size wires was used.

The first part of each cable to be laid was the 2.5 mile (4 km.) shore end section on the Avalon side. This was done from a barge equipped with a large power-driven reel upon which the cable was first wound. At the Avalon end the barge was anchored near shore and the end of the cable pulled up through the underground ducts and into the office by means of a tractor. Following this the barge was towed out to sea, the

cable being unwound from the reel. Prior to the laying, marker buoys had been placed to indicate approximately the location of the ends of these shore end sections. To the end of the cable a section of chain and a long rope was attached, the other end of which was made fast to a buoy.

The main portion of the cable was laid by the government cable ship "Dellwood." This ship, which has a length of 330 feet, (100 meters) is well provided with the usual cable handling equipment.

In laying the main portion of the cable the ship was first anchored about half a mile (about 1 km.) off the San Pedro shore opposite the cable hut and the end of the cable pulled ashore with the aid of the barge, tug, and other small craft. The ship then started on its course paying out first the shore end, then the intermediate and finally the deep sea cable, all of which had previously been spliced together. On reaching the 1800-foot (550 meter) depth line on the Avalon side, the ship was stopped, the remainder of the deep-sea cable cut off and the end spliced to the intermediate type. Laying was resumed until the buoy fastened to the shore end was reached. The ship was again stopped, and the end of the cable previously laid was hoisted on board. The intermediate cable was then cut and spliced to the shore end, after which the completed cable was dropped overboard. Both cables were laid in essentially the same manner.

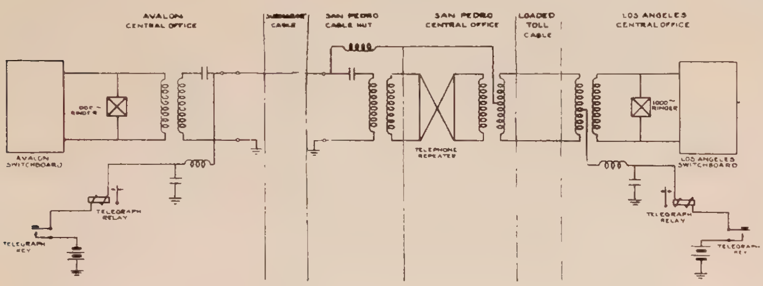

Fig. 12

As the balance of the circuit from the cable hut to Los Angeles had been provided in advance, it was possible to communicate between the ship and shore points as soon as the end of the cable was brought into the hut and the connection established there.

While the cable was being laid, a number of conversations were held between company officials on board the ship and persons in and around Los Angeles and San Francisco. As soon as the final core splice was made communication was established between Avalon and Los Angeles and two hours later a conversation was held with American Telephone and Telegraph officials in New York.

At present each cable provides one d-c. telegraph and one voice-frequency telephone circuit, the circuit arrangement being shown in Fig. 12. Figs. 13 and 14 show the impedance and attenuation respectively of the East Cable.

Although not imposing as regards total length or depth of water encountered, the performance of this cable will be watched with great interest as it marks an important forward step in the development of submarine cable manufacture in this country.

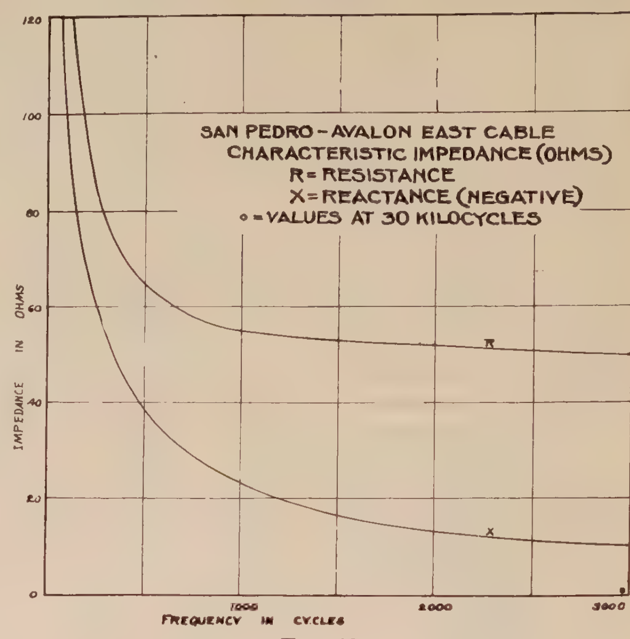

Fig. 13

While this discussion has covered only a few of the outstanding applications of long distance telephony on the Pacific Coast, it will serve to indicate the way in which some of the most recent advances in the art constantly developed by the Bell System have been employed. It is by means of such recently developed instrumentalities that the people of the Pacific Coast now are able to talk to all sections of the United States, bringing the inhabitants of this broad country into an intimate contact that cannot fail to be of great commercial and social benefit.

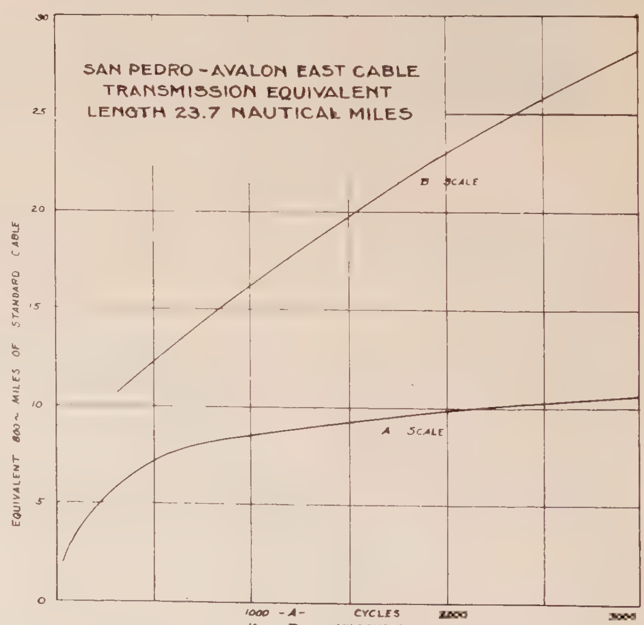

Fig. 14

Recent Developments in Carrier-Current Communication

BY LEONARD F. FULLER

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***Review of the Subject.**—Carrier-current communication over transmission lines has been developed to a point where its practicability and value are thoroughly established.*

This paper discusses several recent developments in apparatus and methods of operation.

Carrier-frequency energy flow along the line is discussed briefly to give a mental picture of the electromagnetic and electrostatic conditions existing.

Standard 50 and 250-watt apparatus are shown in the illustrations and described briefly.

CONTENTS

CARRIER-current communication over transmission lines is being adopted rapidly not only as an auxiliary to existing wire telephones, but as the only means of direct communication for some recently constructed lines.

As our accumulated experience has increased the desirable frequencies and the range of sets of various powers over lines and networks of different types have become fairly well established.

Field experience to date has shown the practicability of transmitting carrier current over power systems with reliability and certainty. The method has been proved basically sound.

Recent Developments

The next steps in development are improvements in the apparatus, both mechanical and electrical, including those features which give greater operating convenience and flexibility.

Remote control of the apparatus is an example. Early sets were designed for control distances up to 250 ft., which is sufficient for the usual conditions encountered when the operator and apparatus are in the same building, but remote control attachments now available increase this distance to several miles. Thus a dispatcher in a city office building can control the carrier-current set miles away in an outlying suburban substation.

A modification of the foregoing is to retain the control of the carrier set at the station at which it is installed, but to have it arranged so the operator at the station can plug in the voice control on any one of a number of the company's wire phone lines. Such an arrangement allows distant stations to communicate directly with anyone in the main office.

Calling is accomplished on existing carrier-current channels either by one or more gong bells operated by a local relay, or by means of a loud speaker which permits direct voice or howler calling. This method is employed in the Great Western Power Company and Pacific Gas and Electric Company equipments, while the relay and call bell method has been generally employed in eastern installations.

Each method has its inherent advantages and disadvantages. The loud speaker cuts the time for short dispatching orders almost in half when operators are constantly within hearing distance. In such cases calling and answering calls are dispensed with. The dispatcher gives an order and the station to which it was directed repeats it. The Great Western Power Company has used this method for over a year and the Pacific Gas and Electric Company has also found it satisfactory.

If there are several carrier sets on a system, which intercommunicate frequently, it is often annoying and generally undesirable to have a loud speaker talking when its station is not concerned with the conversation. In one installation there was an objection to the loud speaker, not because of undesired conversations which did not exist in this case, but because of the line and electric storm noises which were reproduced. Relay and gong bell ringing is necessary in such cases.

Selective ringing is a further refinement which may be employed when code ringing of the gong bell would cause annoying and unnecessary disturbance at several stations of which only one was desired.

Time limit attachments are often furnished with the calling relay system to prevent electric storms and other high-frequency disturbances from ringing the gong bell. Code ringing is possible with such attachments, since the time limit feature is automatically inoperative after the first signal which must be a long dash. It may be followed by any desired dot and dash combination.

An excellent calling system is a relay with time limit attachments arranged to connect a loud speaker in circuit at the end of the long dash above mentioned. A gong bell may be added if desired. In this way the loud speaker does not reproduce undesired noises, but comes into service automatically for any speech or code calling.

A selector system may be added to such a combination. In this case the loud speaker is connected in circuit only when its station is called, but after being connected, the message may follow immediately if desired, with the resultant saving in time.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Cal., October 2-5, 1923.

We are thus able to utilize the desirable features of the loud speaker system and remove those considered detrimental.

The calling relays are quite reliable when equipped with the time limit feature. They require very little energy and will operate with less than is required for satisfactory speech. Thus we can ring over any line over which we can talk.

All our installations are simplex. That is, the operator throws a tumbler switch or operates a foot pedal to connect the apparatus for talking or listening. This method has met with success wherever installed. It rarely takes an operator more than the first day to become used to the scheme of things.

The writer once saw a laborer working about a station called to the carrier phone set to receive a personal message from a man he had known in the army who happened to be visiting the station at the other end of the line. After operating the talk-listen button for him for the first few sentences no more assistance was required and the conversation proceeded vigorously.

This was a case where men who had not talked with each other for two years and who had never seen a carrier phone set before, found simplex operation so easy that they carried on an animated conversation over a 200-mile line for some time.

Duplex operation, except over short distances with sets of very low power, complicates the apparatus and decreases its reliability out of all proportion to the slight advantage gained. The users of this equipment are mainly station operators who soon grow accustomed to the man at the other end of the line and the semi-routine character of a large portion of the traffic handled.

Telegraphy is a valuable adjunct which may be added to carrier-current sets. It may be by either interrupted or continuous waves. The latter are preferable in emergency work because they will permit telegraphic communication under extremely severe line conditions.

The writer has received continuous wave telegraph signals at Pit River from the Vaca-Dixon substation 202 miles distant with all 6 line conductors grounded at several points although telephony and interrupted wave telegraphy were altogether out of the question, not a sound being heard in the phones.

For communicating over very noisy lines and during bad electrical storms interrupted waves may be used, but continuous wave heterodyne reception is probably preferable.

In starting telegraphy on an existing carrier-current telephone channel it is preferable to begin with a list of code signals for the common orders and use these frequently while the operating personnel are learning the telegraph code.

A speed of only 5 words per minute is of great value in emergencies when all other forms of communication may have failed. Most men can learn to send and receive at this speed without great difficulty. The higher speeds used in commercial telegraphy are learned easily and well only by rather young men.

Energy Transfer and Flow

Irrespective of the use to which the carrier-current energy is put at the receiving station, the method of transferring it to and from the line is the same.

At the transmitting station a carrier-frequency current is fed into the line. This results in a potential difference either between all line conductors and earth or between conductors. To date commercial installations have utilized the former method.

The electrostatic field due to this potential difference expands or travels down the line toward the receiving station at a velocity depending upon line constants. Usually this is not far below that of light in free space.

If the carrier frequency is 30,000 cycles per second, a half cycle will last 1/60,000 second and the static field of one half-cycle will have extended for about 3 miles along the line before the reversal of polarity due to a succeeding half-cycle commences.

If our eyes could see electrostatic fields and we stood at any point along the line, while these things were occurring, we would see nearly three miles of field slide by at about the speed of light, with the line positive with respect to earth, followed by an equal length in which the polarities were reversed.

If the line is short enough to allow the static field to travel to the receiving station while it is still being formed at the transmitter, the load drawn by the receiver will effect the power output of the transmitter. That is, the input impedance of the line will be varied by the receiver or load impedance.

This phenomenon, which is always observed at power frequencies on lines of present day length, is rarely observed at carrier frequencies. The lines are obviously too long to permit it.

Thus the energy delivered to the line at the sending station becomes wholly detached from the transmitter and is either partly absorbed by the receiver or frittered away entirely in line losses.

The most common method of charging the line at the transmitter is to erect a "coupling wire" in the vicinity of the line conductors. When this is raised to a given carrier-frequency voltage with respect to earth the conductors assume a potential corresponding to their relative positions in the static field.

Various types of coupling condensers have also been employed with mica, porcelain, and other dielectrics. Such condensers are connected between the carrier-current transmitter and the line, the current passing through them charging the line with respect to earth.

At the receiving station various arrangements capable of extracting energy from the electrostatic field may be used. Coupling wires, large wire loops, coupling condensers and combinations of them may be employed. At the present time the coupling wire method is preferable for both transmitting and receiving, due not only

to its reliability, simplicity and ease of inspection, but also to its low first cost.

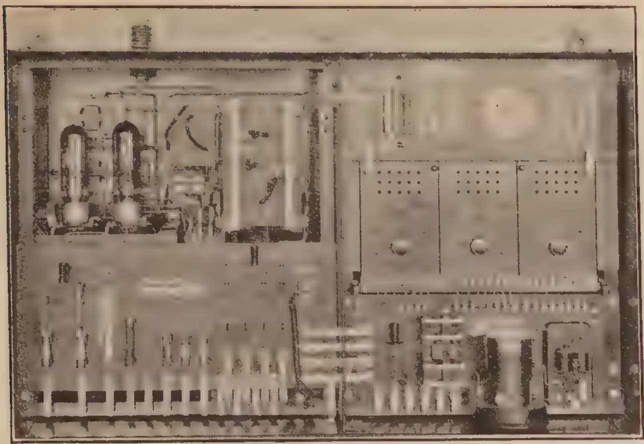

Fig. 1—Transmitter-Receiver for 50-Watt Carrier-Current Telephone
The calling relays are mounted on the section at the right.

Fig. 2—250-Watt Carrier-Current Transmitter
Having master oscillator, power amplifier, voice amplifier and modulator tubes.

Station Apparatus

The sending and receiving station apparatus is much like that used in commercial radio communication with such modifications as are desirable for power system use.

Fig. 1 shows a typical carrier-current equipment having a power output of 50 watts. The transmitter is mounted at the left, the receiver at the right.

Power is supplied to the transmitting vacuum tubes at 1000 volts d-c. by a small motor generator driven by the station a-c. or d-c. supply as determined by local conditions. The receiving tubes are operated from storage batteries in the customary way.

Fig. 3—250-Watt Carrier-Current Receiver
Showing tuning adjustments and calling relays.

This equipment is used for telephony over the shorter lines. Its actual range depends upon the arrangement of the system. Transformers, taps, cables and associated low-voltage lines all affect the situation. Field experience has accumulated to such an extent however, that the analysis of such networks is now readily accomplished.

More powerful sets of 250 and 500 watts carrier frequency power output are built for the longer and more difficult lines. Communication by the 500-watt

Pit River set of the Pacific Gas and Electric Company has been received over 410 miles of line.

These equipments are built in several units.

The 250-watt set comprises:

(1) A power panel on which the motor generator starter, switches, fuses and instruments are mounted.

(2) The transmitting apparatus, cabinet housing all necessary vacuum tubes, instruments, coils, relays etc.

(3) The receiver cabinet.

(4) The motor generator.

(5) The operator's desk phone set and a loud speaker when used.

Figs. 2 and 3 show portions of this equipment.

Both the 250 and 500-watt sets are of the master oscillator type, that is, the carrier-frequency currents are generated by a small tube used to excite a larger one. The output of this power amplifier is modulated in accordance with the voice by another or modulating tube and then delivered to the coupling wire.

This method gives a substantially constant carrier frequency irrespective of line conditions and maintains a better voice quality than is possible with self-exciting tubes when forced to operate under adverse conditions.

The sets of the Great Western Power Company and Pacific Gas and Electric Company are not of the mechanical form shown in Figs. 2 and 3 having been developed in cooperation with the power companies prior to the design of the present standard equipments.

SUMMARY

In this paper I have attempted to outline briefly and without irrelevent technical or descriptive detail, the outstanding features of carrier-current work on transmission systems as we know it today.

Our present technique has the background of the older radio communication. Active commercial experience on high-voltage lines has been of shorter duration, but amply sufficient to prove the method technically and economically sound, and to demonstrate a few of the many uses the future will find for it.

SUPER POWER SYSTEMS PROJECTED

In France the water-power possibilities of the mountainous regions have been carefully studied and several important new projects are taking form. In the northwestern portion of that country, where only steam power is available, there has been much development in the shape of steam plants tied together by high-tension transmission lines. The whole of France is working toward the ultimate tying together of power undertakings in various parts of the country by ultra-high-voltage transmission lines, as has been commented upon in recent issues of *Commerce Reports.*

Both Italy and Spain are adding to their hydroelectric capacity, as the money market makes it possible for them to finance the undertakings on a satisfactory basis. Italy, especially, is active in utilizing its water powers, and American interests will participate in some of the financing.

Japan is continuing its rapid development of its water-power resources and the tendency is toward a few large operating companies serving the whole of the nation. Of late there has been a proposal made by certain interests to promote a privately owned superpower scheme by a consolidation of the existing operating companies. It is not unlikely that in a few years' time the number of hydroelectric projects in the main island of Japan will feed into an ultra-high-voltage trunk line running its whole length.

In Australia, New Zealand, Norway, Sweden, India, and even Russia there is the same tendency to utilize all feasible water powers and to concentrate in efficient superpower steam stations the power supplies needed. In Sweden and New Zealand the Governments are developing what are really superpower schemes for these respective countries. In Australia the State of Tasmania has a state-owned power system that is reaching out to cover the whole island, and in the State of Victoria the Morwell steam project, utilizing brown coal as fuel, is broadening its plans to supply power to a considerable area of that State. Russia is making progress on a plan to build four large plants, partly hydroelectric and partly steam, to serve areas in central and northwestern Russia.

UNITED STATES LEADS IN HIGH-TENSION PRACTISE

American manufacturers through their experiences in the home market have developed high-tension designs and practises in voltages exceeding those to which most foreign manufacturers are accustomed, and this fact makes it possible for them to offer tried equipment in the markets of the world with less competition from foreign manufacturers than exists in many other electrical lines.—*Commerce Reports.*

CENSUS OF ELECTRIC LIGHT AND POWER STATIONS

The Department of Commerce presents preliminary figures relating to the kilowatt hours of electric current generated by central electric light and power stations, both commercial and municipal, and by electric railways, in 1922, as compared with 1917 and 1912. These figures do not include the output of electric plants operated by mines, factories, hotels, etc., which generate for their own consumption, or those operated by the Federal Government and state institutions.

The amount of current generated in 1922 aggregated 46,307,536,711 kilowatt hours, as compared with 32,678,806,061 kilowatt hours in 1917 and 17,621,808,893 kilowatt hours in 1912, an increase of 38.6 per cent from 1917 to 1922, and of 157.1 per cent for the ten-year period 1912 to 1922.

Some Experiences with a 202-Mile Carrier-Current Telephone

BY E. A. CRELLIN

Member, A. I. E. E.

Pacific Gas & Electric Company, San Francisco, Calif.

ON April 11th, 1923, the Pacific Gas and Electric Company placed in operation a carrier-current telephone system between Pit River Power House No. 1 and Vaca-Dixon substation. This system utilizes the twin-circuit 220,000-volt transmission lines between the two points for a conducting medium and is for use primarily by the operating department in directing the operation of the power houses in the Pit River development together with the transmission lines which carry the energy southward to the distribution center at Vaca-Dixon substation. With the commencement of work on Pit River Power House No. 3 an increasing volume of messages is being received from the construction and auditing departments for transmission to the general offices of the company, and it is already apparent that additional carrier-current telephone sets will be required, one at the base of construction operations for Power House No. 3 and one at Claremont substation in Oakland to relieve the congestion on the wire line between Vaca-Dixon substation and the load dispatcher's office.

During the six months from October 1922 to the inauguration of the carrier-current telephone, the operation of the Pit-Vaca transmission system was directed by wire lines. In the absence of direct wire communication between the load dispatcher's office at Oakland and the power houses in the Pit River system, it was necessary to relay all messages one or more times which introduced a considerable delay and was subject to error, especially in view of the inductive interference usually encountered on telephone lines paralleling transmission lines. Since the carrier current telephone was placed in operation in April it has answered all dispatching requirements, and as the operators become more and more familiar with the peculiarities inherent in such a system its many advantages over the wire lines become more and more apparent.

The system is coupled to the transmission line through a single-wire antenna about 1800 feet long. This wire is attached to the twin vertical circuit transmission towers at a point on the center line of the towers and at the elevation of the middle arm. The main ground system for the station apparatus is also used for the carrier-current telephone ground and no counterpoise is used. The frequency adopted, after a series of tests ranging between 12,500 cycles and 85,000 cycles was 50,000 cycles. This is free from all outside interference and gives the best combination of signal strength and voice modulation.

The transmission equipment is similar to that installed in several of the high-powered broadcasting stations in some respects, and employs two 250-watt oscillator tubes, two 250-watt modulator tubes and a 50-watt speech amplifier tube. It is appreciated that this is a relatively high-powered transmitter and for all normal conditions of operation such as an amount of power is not necessary. However, communication is more urgently needed during periods of abnormal condition than at any other time and it is then that this excess power is called upon to get the message through.

Calling is accomplished by mounting a standard telephone microphone in the horn of the loud speaker which, when the calling circuit is completed, will oscillate and howl in much the same manner that the ordinary telephone will howl when the receiver is placed against the transmitter. This gives a very loud note whose pitch will depend upon the natural period of oscillation of the diaphragms and which is clearly audible in all parts of the station. Ordinarily, it is not necessary to use the calling system, as the receivers are always in service and the operator near the set so that the loud speaker simply talks at him and he starts up his set and talks back.

The system is arranged for simplex operation and all that is necessary is to operate a small telephone switch which energizes a contactor to connect either the transmitting or receiving set to the antenna, thus permitting talking or listening. Some tests made with a view to establishing the possibility of operating as a duplex system are described further on in the paper.

Normal rating of the 250 watt tubes used is based upon a filament lighting supply of 11 volts and a plate pressure of 2000 volts. With the transmission line in operation and all conditions normal it is possible to obtain an antenna radiation of 6.2 amperes with the tubes operated at rated voltage. This gives a received signal at the other end of the 202 mile transmission line considerably louder than necessary. The receiver is a standard regenerative set using two stages of audio frequency amplification to operate a loud speaker, and speech can be heard all over the power house when maximum amplification is employed. For regular service, therefore, the filament lighting supply on the transmitter is reduced to about 10.4 volts and the plate pressure to 1600 volts, which gives an antenna radiation of approximately 5.0 amperes.

The tubes are extremely sensitive to variation in

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filament voltage and it has been found by experience that 10.4 volts is about as low as it is desirable to operate. Below that point it is sometimes difficult to start oscillation and sluggish operation means delay in acknowledging receipt of a message. Communication has been carried on with a radiation as low as 2.5 amperes, but with poorer modulation. With a 5-ampere radiation at the sending station the receivers are set for minimum amplification and no difficulty is experienced in handling messages.

To one unaccustomed to listening to a loud speaker, the messages are often very hard to understand and some difficulty was at first experienced by the operators who had not had previous experience with loud speakers. However, this was easily overcome after a week or so of operation of the phones and it is now rarely necessary to repeat a message. Routine dispatching is carried on more easily with the carrier current telephone than with the wire phone due to absence of inductive interference. A considerable volume of accounting and construction department messages is handled over the carrier current telephone and this gave trouble in some instances when it was necessary to transmit unfamiliar proper names. It usually resulted in spelling and due to the difficulty in distinguishing between certain of the consonants which are similar in sound, this did not solve the problem. The method now generally used is to try the voice once and if any difficulty is experienced the name in question is transmitted by telegraph code. The operators have been supplied with a chart on which the Continental code is printed in large clear letters and those who have not memorized the code simply pick out a letter at a time and transmit it by means of the calling key. This may sound slow but in reality it is quicker and more positive than several voice repetitions of the letters composing the name in question. Naturally more speed is attained by the operators familiar with the code, and without exception all of the operators are taking a very great interest in the carrier current telephone and are practising with the code during the shift between midnight and five o'clock in the morning when other duties are at a minimum. It is desirable that the operators become used to the telegraph code and able to transmit five or ten words a minute because certain forms of line disturbance make voice transmission difficult and still permit of distinguishing the letters of the telegraph code which comes through as a high-pitched note of constant tone, readily distinguished from other noises. It is also possible to transmit the code when abnormal conditions make it difficult to secure sufficient radiation to give good voice modulation.

All operation of the carrier-current telephone to date has been carried on with one of the 220-kv. transmission lines still incomplete. The first work was done with two transmission lines complete from Vaca to Williams, a point about 50 miles north, and a single line from Williams to Pit, about 150 miles. At Williams the two lines were tied solidly together. The copper for the second line was strung in place between Williams and Cottonwood, about 90 miles, but men were constantly at work upon the line and consequently it was solidly grounded at each tower on which a man was at work. Grounding this parallel line did not affect communication in any manner on the other line.

At present two three-phase circuits are in operation from Vaca to Cottonwood approximately 140 miles with a single circuit from Cottonwood to Pit River approximately 60 miles. The circuits are tied together solidly at Cottonwood and men are now at work on the second circuit between Cottonwood and Pit. A special test was recently made with one three-phase circuit solidly grounded at Vaca and the other circuit clear, both being tied together at Cottonwood, power, of course, being off the lines. No appreciable difference from usual operating conditions was noted in ability to communicate between Pit and Vaca.

Recently one wire on the completed three-phase circuit between Cottonwood and Pit River became grounded due to failure of a piece of insulator-hardware and resultant dropping of the wire on to the tower. This left only two wires completely insulated between Pit and Vaca with a ground on the third, but no difficulty was experienced in carrying on communication.

Communication cannot be carried on with three-phase grounds at either or both ends of the transmission line. Also, all three wires were recently grounded at Hat Creek, about three miles distant from Pit toward Vaca and communication could not be carried on. At least one wire, insulated from ground, between the two points is necessary for successful communication by carrier-current telephone.

When the transmission line is dead and isolated by opening the disconnecting switches at each end of the line considerably more power output from the transmitter is required than when the line is connected to the transformers and energized at 60 cycles. This difference is probably due to the change in transmission line constants by the removal of the reactance of the transformers which in turn cuts down on the current radiated from the antenna. When the transmission line is thus isolated the station operators immediately increase the power output of the carrier-current telephone transmitter to its maximum by raising plate and filament voltages to 2000 and 11 volts respectively. Communication is then carried on as usual and no difficulty is experienced in directing operations.

In order to carry on duplex communication, that is, to be able to send and receive at the same time, it is necessary to employ two antennas, one for the transmitter and one for the receiver. Some tests were recently made to establish the effectiveness of various types of receiving antennas. At Vaca it was possible

to receive messages from Pit River when using a bushing type current transformer on one of the 220-kv. line oil switches as an antenna. The leads from this current transformer are carried in lead covered cable about 300 feet to the substation wall, thence in rubber-covered wire in iron conduit to the switchboard, an additional 40 feet. The receiver was hooked on to one terminal of the line ammeter on the switchboard. Only the reactance of the ammeter coils was between the antenna and ground. The signals received were clear, but weak. It was necessary to use the head phones with all the amplification at hand to bring it in strong enough to understand. Stronger signals were received when using the secondaries of one of the 110-kv. potential transformers on the 110-kv. bus but they were not considered strong enough for use by the operators. As a matter of interest, one test was made using one side of the lighting circuit for an antenna. Very weak signals were heard which might have been brought in strong enough to be understood had a couple of stages of radio frequency amplification been available in addition to the two stages of audio frequency amplification which were employed. This reception was through three power transformers, *i. e.*, the main bank which steps down to 11,000 volts for the synchronous condensers, the station bank stepping from 11,000 to 440 volts and the lighting bank stepping from 440 to 110-220 with the mid point on the secondary grounded.

Finally a separate receiving antenna was strung at Vaca and also at Pit. These antennas were each about 250 feet long and placed in the most convenient temporary location. Excellent reception was obtained and the loud speaker could be operated at full volume from the short auxiliary antenna. The transmitter at Vaca was then lowered in frequency to about 30,000 cycles, with the Pit transmitter remaining at 50,000 cycles. With the Pit receiver tuned to 30,000 cycles it was not possible to transmit at 50,000 cycles while receiving because the transference of power between the sending and receiving antennas was so great as to blanket out the received signals. When duplex operation was tried at Vaca, the transference of power was sufficient to arc across the grid condenser which is a 23-plate variable condenser in the receiver used. It would seem that duplex transmission is not practical with two antennas when using transmitting sets of the power output necessary to successfully talk over a 202-mile transmission line, and accordingly no further tests were undertaken.

During the initial installation of the Pit-Vaca carrier-current telephone several tests were made between the Vaca-Dixon substation and the Fourth Avenue substation of the Great Western Power Company in Oakland, where a similar carrier-current telephone set is installed. There is no direct transmission line between the two substations. The Great Western feeds the Pacific Gas and Electric Company through a 60-kv. transmission line which is carried for about three miles on the same steel tower line as the 110-kv. transmission line and on the same right of way as the 110-kv. twin circuit Oakland-Big Bend transmission line to which the carrier-current telephone is coupled. The 60-kv. feeder goes into the Ridge substation of the Pacific Gas and Electric Company, and thence on to the Claremont substation. There is a parallel of some three miles or so between the 60-kv. Ridge-Claremont line and the 110-kv. Claremont-Vaca line where the two circuits are on the same right of way. At Claremont the 60-kv. and 110-kv. are tied together through auto-transformers.

Conversation is readily carried on between Fourth Avenue and Vaca, a distance of about 60 miles, and during the initial tests between Pit and Vaca, the Great Western operators were able to listen in and understand what was being said at Pit. It is believed that this is a record for distance for carrier-current telephone transmission, somewhat over 260 miles with no direct transmission lines connecting the last 60 miles to the transmitter.

The Pacific Gas and Electric Company is entirely satisfied with the results of the carrier-current telephone secured to date. Many conditions of operation have been met and the carrier-current telephone has at all times been ready to perform the duties required of it. The principal difficulty to be overcome is that of understanding the loud speaker which is simply a matter of becoming accustomed to the voice as reproduced in a loud speaker horn rather than in a telephone receiver. The operators in general seem to prefer the loud speaker to the head phones, and rely upon it at all times to receive their messages.

As stated before, the volume of traffic over the carrier-current telephone is steadily increasing and plans are already being laid for the installation of additional sets at Pit River Power House No. 3 and Claremont substation. The last named set will be remote-controlled from the dispatcher's office in Oakland and a relatively small investment in apparatus will obviate the necessity of a 260-mile metallic telephone line to handle the operation of plants in the Pit River development, and results achieved to date indicate that it will be equally reliable and a much more quiet phone to talk over.

DANISH PEAT MAY SUPPLY ELECTRICITY

Employment of dried-peat fuel instead of coal for the production of electricity in Denmark is being promoted by the local subsidiary of the German Siemens Co. According to one of the leading Danish experts on fuels, Denmark's entire consumption of electricity, both for lighting and industrial power purposes, could be supplied by utilizing the country's extensive peat marshes. The city of Gudenas is said to be negotiating with the Siemens Co. regarding the possible utilization by the municipality of peat fuel for generating electricity. (Minister John D. Prince, Copenhagen, September 8.)

The Cooling of Electric Machines

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THE disposal of the heat resulting from the electrical and mechanical losses in any electric machine is always an important item to the designer as well as to the operator of the machine. These losses appearing all in the form of heat must be transferred from their source with a temperature gradient not to exceed the maximum safe operating temperatures. These maximum temperatures are limited by the insulation necessary to insulate the windings.

In the early days of machine design the generators, being principally of the engine type, were slow in speed and hence large in size. Due to the large surfaces, it was comparatively easy to liberate the heat with a low temperature rise. In fact with these old machines it was usually unnecessary to provide for additional ventilation other than that due to natural ventilation and windage of the rotating element. The ratings on many of these earlier machines were limited not by the temperature rise but by the performance such as commutation or regulation.

The development of the high-speed turbo-generator and the hydroelectric generator resulted in a machine of greater rating, hence greater losses, with a physically smaller machine than was used with the direct engine drive. This concentration of losses in a smaller space was possible only by greatly improving the ventilation. Today the commutation and regulation limitations of a machine have been practically removed so that the temperature limitation is usually the dominating factor in setting the maximum rating of electric machines. Thus to design the most economical machine, full consideration must be given to the temperature obtained at its rating. A machine with temperatures above the maximum permissible temperatures will not have a long life; on the other hand, a machine with temperatures too low mean an economic waste of material.

Disposal of the Heat Losses

The heat resulting from the internal losses of an electric machine must eventually be transferred from the machine to the air, water or the earth. This transfer of heat may be accomplished by many means. A direct system of cooling can be used such as the circulation of air or water over the heated surfaces with the heated air or water discharged at a point remote from the intake supply. An indirect system is often used for cooling a machine, such a system utilizes a fluid such as air, oil or water to "ferry" the heat from the surfaces of the machine to the outside supply of air or water. This transfer of heat may be made in several stages. Thus in an oil-insulated water-cooled transformer the heat "picked up" by the oil is transferred to the water in the cooling coils. This water then carries away the heat and distributes it either in the earth or in a body of water.

The most common system of cooling used with electrical apparatus is the direct air system. This system is especially adapted to rotating machines due to the mobility of the air. For high-voltage apparatus, such as transformers, oil is used for insulation purposes, so that the indirect system of cooling must be used. The oil merely acts as a "heat ferry" and carries the heat to the water-cooling coils in the case of a water-cooled transformer or to the ventilating surfaces in the case of a self-ventilated transformer.

Hence, one of the principal factors in the cooling of electrical apparatus is the determination of the temperature differences necessary to transfer the heat from the surfaces of the machine to the cooling fluids and from one fluid to another. The purpose of this paper is to give a summary of the various rates of heat transfer necessary for the predetermination of the machines operating temperature. Since air is the most common cooling agent it is given the greater consideration. The data given, unless noted to the contrary, are the results of experimental tests under the writer's direction and much of the data have been hitherto unpublished.

Coefficient of Heat Transfer

The rate at which heat is transferred between a surface and a gas or liquid is called the coefficient of heat transfer or the heat dissipation constant. Throughout this paper the coefficient is defined in terms of watts per square inch of surface per deg. cent. difference between the surface and the fluid. This heat transfer constant is the same for a heat flow from a surface to the fluid or from the fluid to the surface, the direction of flow being dependent only upon the temperature gradient.

Dissipation of Heat by Natural Ventilation and Radiation

The liberation of heat from electrical apparatus by natural ventilation and radiation is always a factor in limiting the operating temperatures. Many small industrial machines are operated totally enclosed, in which case all the heat must be dissipated by natural ventilation and radiation, also transformers, wires, cables and bearings are quite commonly cooled by this same agency.

A. *Radiation.*

The law governing the heat loss from a hot body by radiation has been thoroughly investigated by many authorities.

Abridgement of paper presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 27, 1923. Complete paper available without charge to members.

The values of the heat loss radiated at various temperatures are shown plotted on Fig. 1. These curves show a considerable difference in the unit heat loss depending upon the room wall temperatures, also the rate of heat radiation increases considerably with increase in temperature rise.

B. *Natural Convection.*

The liberation of heat from a hot surface by natural convection is probably both by conduction and convection. That is the heat for a short distance from the surface is conducted through a thin layer of dead or stagnant air, the outer surface of this air film is set into motion by the expansion of the heated air particles and from here on the heat is ferried away by these convection currents.

Tests made by the English National Physical Laboratory[3] on the convection losses from a plane surface (3 ft. square) with different positions of the heated surface are shown in Fig. 2. As shown the heat loss by natural convection is proportional to the 5/4 power of the temperature rise above the ambient temperatures. These tests were made on both smooth steel and aluminum plates with the same results as shown.

C. *Radiation and Convection.*

1. *Plane Surfaces.* The heat loss by radiation and convection from a plane vertical surface is given on Fig. 3. This surface was 3 feet square and was painted a dull black color. The heat loss from a 9-in. square heater[4] is also shown on Fig. 3 for a black plate and a brass plate.

2. *Corrugated Surfaces*: The use of corrugated surfaces is quite common for oil-insulated transformer tanks. It is thus possible to increase the actual surface several fold over that obtained with the plane tank surface. The increased heat dissipating capacity due to the corrugations is principally due to the action of natural convection currents. The heat actually radiated will not be appreciably increased by the

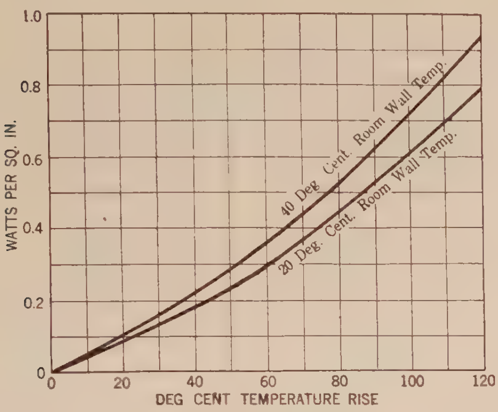

Fig 1—Heat Loss by Radiation from a Black Surface

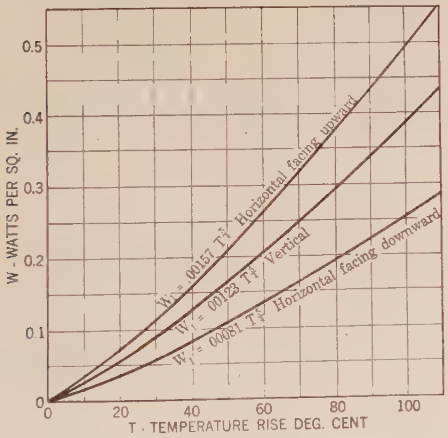

Fig. 2—Heat Loss by Natural Convection in Still Air from a Steel or Aluminum Plate 3 Ft. Square

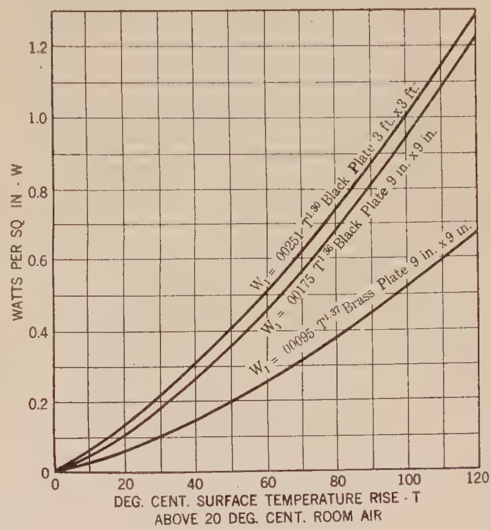

Fig. 3—Heat Loss from Surface of Vertical Plates by Natural Convection and Radiation

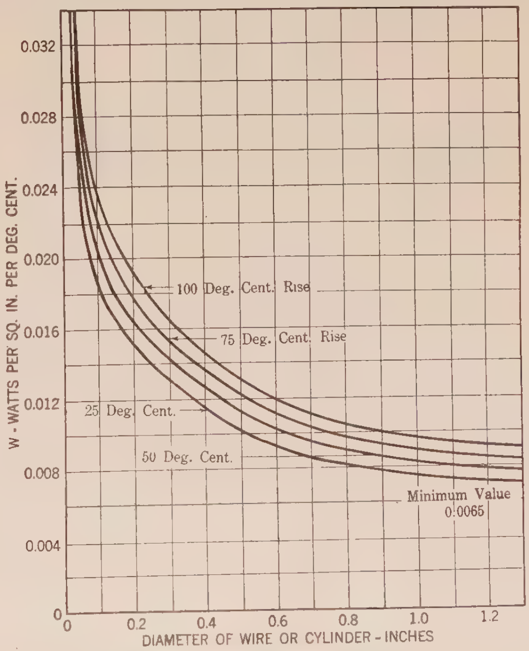

Fig. 4—Heat Dissipation from Wires or Cylindrical Surfaces by Natural Ventilation and Radiation in Still Air Based on Room Temperature of 20 Deg. Cent.

corrugations. The effective radiating surface is the minimum enveloping surface and not the actual surface. Thus the so-called "radiators" used for heating a room or of a type used for cooling the oil in a self-cooled transformer function mainly by convection and not by radiation.

3. *Cylindrical Surfaces*: The dissipation of heat from a cylindrical surface* by natural ventilation and radiation is a function of the diameter of the cylinder or wire.[5] This is shown on Fig. 4. These tests were made with the wires or cylinders suspended horizontally in free air in a large room and no attempt was made to reduce the natural air convection currents found. Thus the smaller diameter wire can liberate the heat at a greater rate per unit surface than the larger wire.

Dissipation of Heat by Forced Air Streams

In order to improve the rating of electric machines, it has long been the practise to use forced air ventilation. Radiation plays very little part in dissipating the heat from the internal motor surfaces. Most of these surfaces are at the same temperatures, hence, the heat interchanged by radiation will be small if any. Thus the cooling action obtained with forced air convection is due almost entirely to the transfer of heat to the air by conduction and convection.

These forced air streams may be produced either by the fanning action of the rotating parts on the rotor, by an external fan or by a combination of the two.

A. Axial Ducts

The cooling of a machine by forcing air to flow through axial ducts in the core is a type of ventilation that is used in many machines especially in railway motors and turbo-generators. Some advantages of this system of ventilation are:

1. The heat may flow rapidly through the iron to the ventilating surfaces without passing through the laminations. This is an advantage since the resistance to heat flow across the laminations is from 30 to 50 times that along the laminations.

2. The air flows through the ducts at a uniform velocity since the cross-section is constant. This gives minimum air pressure for a given average air velocity.

3. Due to the rough surface obtained, a high rate of heat transfer is secured.

4. The core length of a machine will be a minimum for a given magnetic flux.

Some disadvantages of the axial system of ventilation are:

1. A fan or blower is necessary to force the air through the ducts.

2. The axial ducts must be placed in the core where the loss per unit volume is a minimum. This will give a fairly long heat flow path from the tooth zone where the maximum losses are found to the ventilating surfaces of the ducts.

3. Due to the space required by the ducts, the over-all diameter of the core will be increased.

4. The maximum iron temperature will usually be found adjacent to the hottest air, that is near the end of the ducts.

The heat dissipated from the ventilating surfaces of axial ducts is influenced by the air velocity, size and shape of ducts, and the roughness of the duct surface.

Tests on Axial Ducts

To determine the heat loss from axial ducts of various shapes and sizes tests were made upon an experimental model shown on Fig. 5.

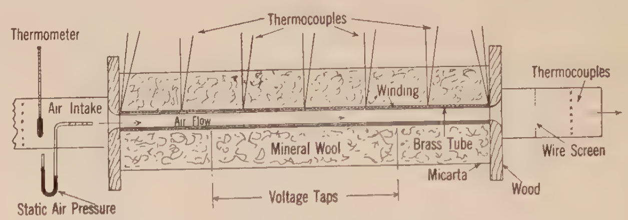

Fig. 5—Apparatus for Determining the Heat Dissipated from Axial Ducts

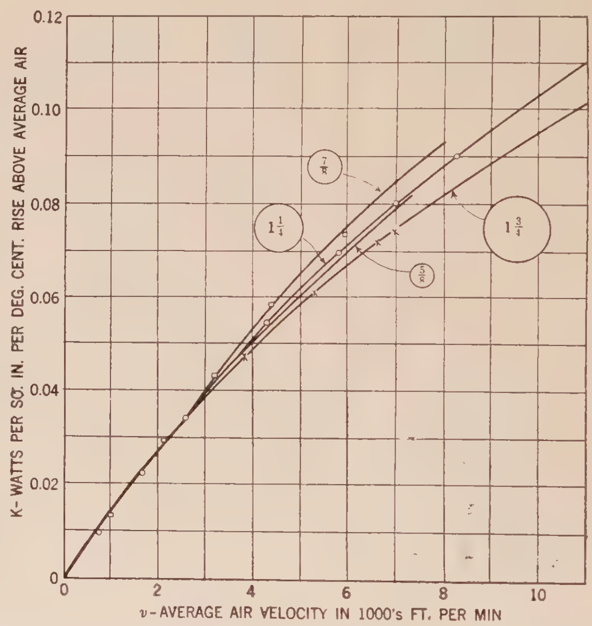

Fig. 6—Watts Dissipated from Interior Surface of Smooth Axial Ducts showing Effect of Change in Diameter

Results and Discussion

(a) Circular ducts of various diameters, smooth surface

The heat transfer constant (K) plotted against air velocity for smooth brass tubes, diameters 5/8 to 1¾ inches, is shown on Fig. 6. There is little difference in this value of (K) for the various diameters, except for the higher velocities. The 7/8 inch duct gives the highest values and the 1¾ inch duct the lowest.

* The total surface is taken as $\pi D L$, where (D) is the diameter and (L) the length in inches.

(b) Effect of change in shape of duct cross-section. Fig. 7 gives the value of the heat transfer constant for three different shapes of ducts. All three have the same periphery. These curves show that the oblong duct has a better heat transfer than the triangular or circular duct also the watts dissipated are more nearly proportional to the air velocity.

(c) Effect of change in air flow through duct. A piece of 0.020-inch fullerboard, 1¼ inches wide and 36 inches long, was placed in the 1¼ inch diameter duct and given a twist of two turns in its full length. This twist forced the air to take a helical path through the duct. Fig. 8 gives the results of this upon the heat liberated. It shows that the air was forced to mix more thoroughly and to scour the tube surface so as to give a greatly increased heat transfer over that obtained with the smooth tube.

(d) Effect of change in nature of surface.

Axial ducts in machines are formed by stacking the laminations in which holes are punched so as to form a

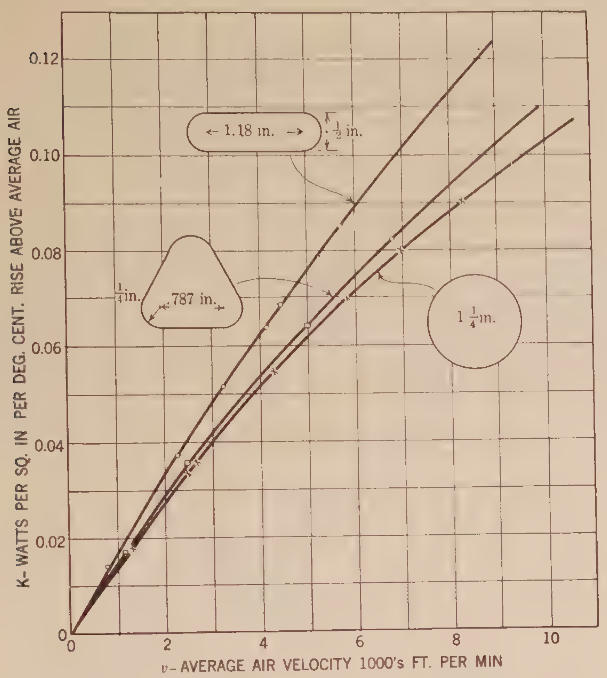

Fig. 7—Watts Dissipated from Interior Surface of a Smooth Axial Duct, Same Periphery

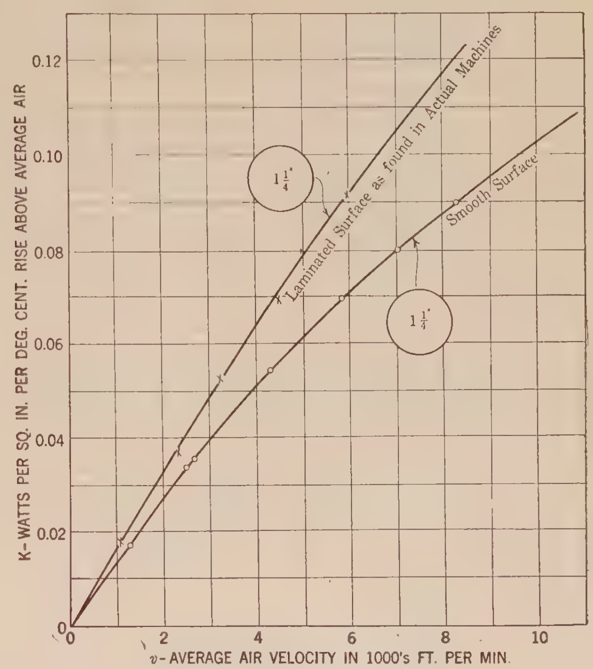

Fig. 9—Watts Dissipated from Interior Surface of Axial Duct, Showing Effect of Surface

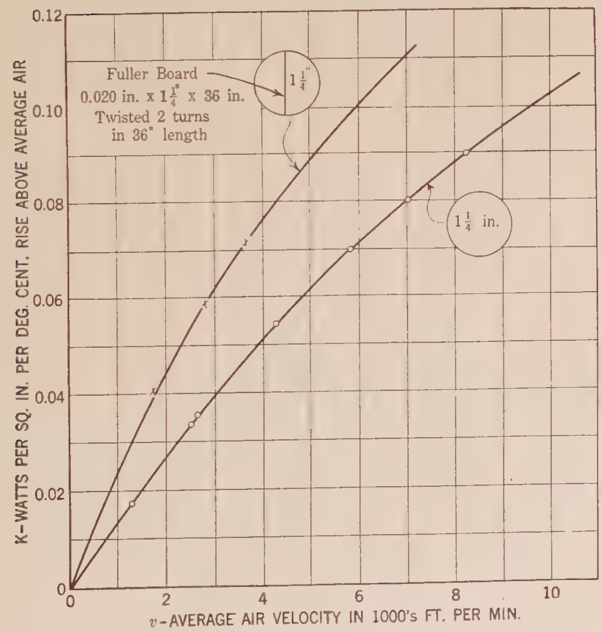

Fig. 8—Watts Dissipated from Interior Surface of Smooth Axial Duct, Showing Effect of Change of Air Path

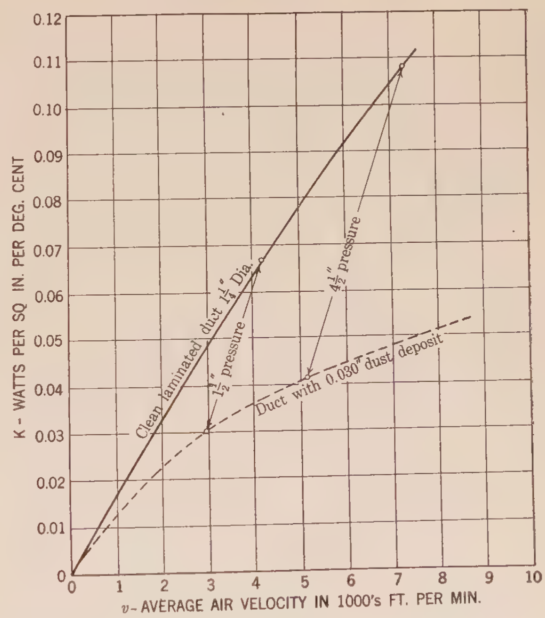

Fig. 10—Effects of Coal Dust Deposits on the Dissipation of Heat from Axial Ducts

continuous system of ducts through the core. The surface of such ducts will not be smooth, due to slight variations in the punchings and in their stacking. To study the effects of this upon the heat dissipated, a series of tests was made with a laminated duct.

Fig. 9 gives the values of the heat transfer constant for the smooth and laminated 1¼-in. diameter ducts. The value of (K) for the laminated duct is appreciably higher than that for the smooth surface duct and is almost proportional to the air velocity. This shows that a rough surface sets up eddies in the air stream, disturbing the uniform air path found in the case of the ducts with smooth surfaces. This tends to prevent a flow of relatively cool air through the center of the duct.

(e) Effect of dust deposits upon the dissipation of heat.

Ventilated machines operating in dirty air will in time have a layer of dust deposited upon the ventilating surfaces. To show the detrimental effects of this dust upon the heating of the machine, the 1¼-in. diameter laminated duct was given a 0.030-in. coating of fine coal dust. The coat of dust deposit, Fig. 10, shows a very great reduction in the heat dissipated especially at high air velocities.

The dust deposit introduced an additional temperature drop which is independent of the air velocity, depending only upon the watts per square inch which must be conducted through this deposit.

B. Radial Ducts

The most common method of cooling the cores of rotating machines is with the use of radial air ducts. Some advantages of the radial duct system are:

1. Radial ducts on the rotating element act as blowers, hence are self-ventilating.
2. Maximum air velocities are found where the losses are most concentrated; that is, in the tooth zone.
3. The air reaches the above tooth zone before it has become appreciably heated and the maximum air temperature is found where the iron losses per unit volume are a minimum.
4. Parallel ventilation of the end windings and the radial ducts is very simply accomplished.

Some of the disadvantages of the radial air duct system are:

1. On rotors having low peripheral speed the fanning action of the radial ducts is small, since the volume of air forced through is directly proportional to the peripheral speed for any given machine.
2. The majority of the heat due to the iron losses in the interior of the iron packet between two ventilating ducts must be conducted to these ducts through the intervening laminations. Since the resistance to the flow of heat across the laminations is 30 to 50 times the resistance to the heat flow along the laminations, it is thus necessary to limit the length of the heat flow path by close spacing of the radial ducts.
3. On high-speed machines especially induction motors, the windage noise may be excessive for certain applications.
4. On machines using small widths of teeth, the duct opening may be too small for effective ventilation and may become closed in service by duct and lint deposits.
5. On small diameter machines the air intake to the radial ducts in the rotor spider is apt to be restricted.
6. The radial ducts increase the gross core length and hence the distance between bearings.

Dissipation of Heat from Radial Ducts

The experimental determination of the heat transfer constants from the surfaces of radial ducts is rather difficult due to the erratic disturbance set up in the air stream by the irregular separating spacers or fingers and to the conductors traversing the air flow path.

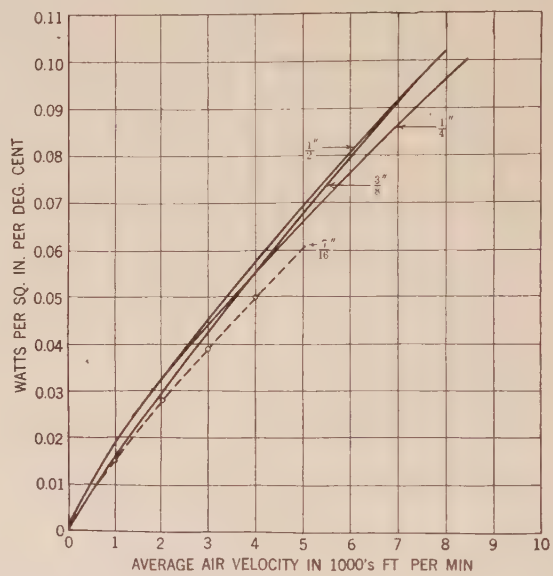

Fig. 11—Heat Transfer from the Surface of Parallel Plates for Various Separation

Also the cross-section of the air path is constantly changing due to the changing diameter.

On machines of large diameter and shallow core depth the air velocity does not change much in passing through the main portion of the core. These conditions can be imitated by two hot plates spaced a definite distance apart with air forced through the separating duct. This air duct varies from ¼ to ½ in., the average radial air duct being 3/8 in. thick.

The results of tests made by the U. S. Bureau of Standards[6] on copper plate type of radiators with three different air separations between them are shown on Fig. 11. There is not a great difference between these three curves and it is probable that the differences shown for the low velocities are within the range of experimental error.

Some preliminary tests[4] made on two smooth parallel hot-iron plates separated a distance of 7/16 in. are also

shown on Fig. 11. These values are lower than those found above. It should be noted that in all these tests the heat dissipation constant is almost directly proportional to the average air velocity. Comparison of the figures given for the 7/16-in. parallel duct with those given in Fig. 6 for the circular axial ducts will show almost the same values.

C. Dissipation of Heat from a Rotating Element

The tests previously given show that for all practical purposes the transfer of heat from the surfaces of axial or radial ducts is almost proportional to the average air velocity forced through these ducts. Experience, however, on the removal of heat from a rotating armature, for example, does not exactly agree with the above observed law. Also no definite data were available regarding effects of forced air convection currents along the surface of a rotating element. For these reasons this phase of the cooling problem was experimentally investigated on a model rotor.

Tests on the Heat Loss from a Rotor

The heat loss from a rotating cylinder was determined

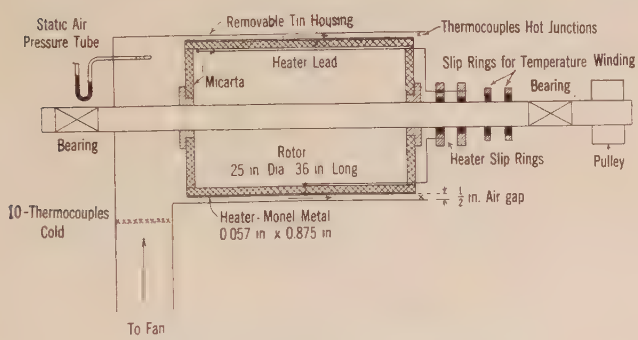

Fig. 12—Apparatus for Determining the Heat Dissipation from Rotors

on an experimental model shown on Fig. 12. This was arranged so that tests could be made with the rotor self-ventilated by removing the housing.

Discussion of Results

Fig. 13 gives the rate at which heat is dissipated for self-ventilation and forced ventilation.

The curve with self-ventilation bends over with high rotor speeds. This indicates that some of the hot air is carried around with the rotor. With forced ventilation, however, the air is forced to pass through the duct. The dissipation of heat is proportional to the number of air molecules passing a given surface and to the temperature difference between the surface and those air molecules. This is shown by the dissipation constant being roughly proportional to the air velocity with forced ventilation.

The curve obtained with forced ventilation and drum stationary agrees very closely with the curves shown on Fig. 9 which gives the corresponding values for an axial duct through punchings.

Curves given on Fig. 14 were all obtained with forced ventilation and the drum rotating at various speeds including the stationary run.

It is seen that with a high rotor speed (1300 rev. per min.) the heat dissipation constant is practically constant for air velocities ranging from 2000 to 6000 ft./min. Conversely it is seen that with the rotor stationary this dissipation constant is practically proportional

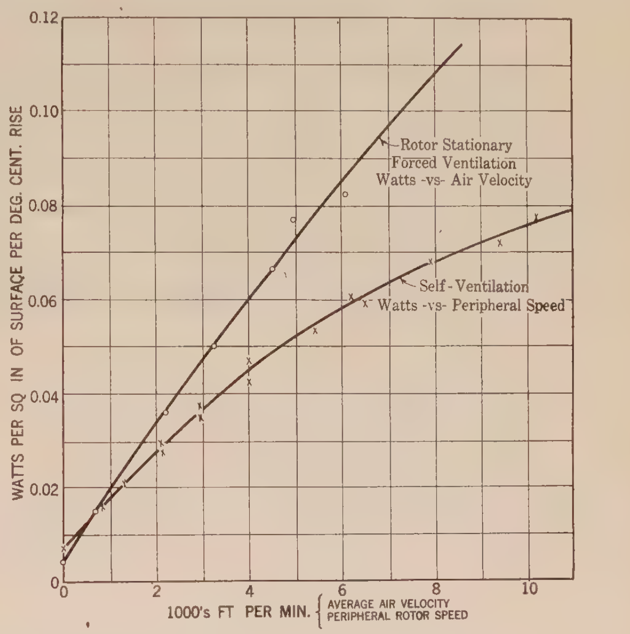

Fig. 13—Dissipation of Heat from the Surface of a Rotor, 25 in. Dia., 36 in. Long

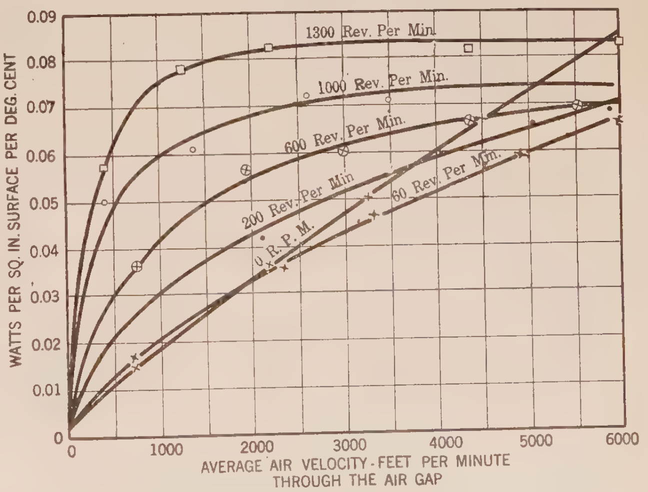

Fig. 14—Watts Dissipated from the Surface of a Rotating Rotor (25 in. Diam., 36 in. Long), with Forced Axial Ventilation through a ½-in. Single Air Gap

to the air velocity through the air gap. With a rotor speed of 600 rev. per min. an intermediate condition is shown.

It has been explained before that the curve on Fig. 13 found with natural ventilation indicates that particles of hot air are carried around the rotor when under

rotation which causes the curve to bend over with high rotor speeds. This same condition happens with the drum rotating in a stator and with forced ventilation through the air gap. In addition to this the rotating surface of the drum at high speeds with its film of rotating air particles offers a very high resistance to the axial flow of air through the air gap.

D. Dissipation of Heat from End Windings

The designer of rotating electric machines tries to reduce the length of the heat flow path in the windings to a minimum. Thus the end windings of these machines are usually ventilated so that the copper loss can be liberated after having been conducted through the insulating material. Due to the great surface available in these ventilated end windings their temperatures are usually lower than the imbedded windings, in fact many short core machines can be cooled almost entirely by these ventilated windings.[8] The tests

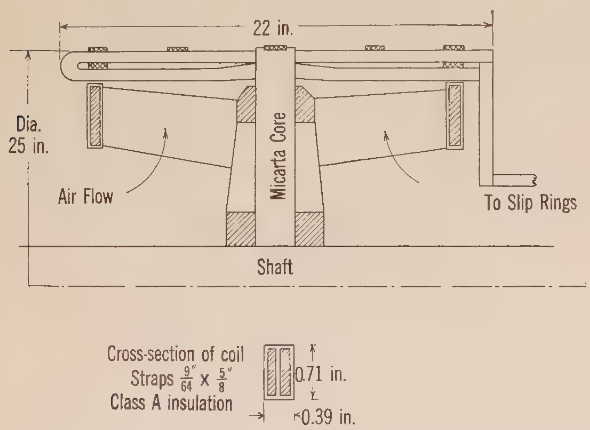

Fig. 15—Experimental Model for Determining the Dissipation of Heat from Rotating End Windings

described below were made for the purpose of investigating the rate of heat transfer from these windings as affected by air velocities and coil arrangement.

(a) *Description of Experimental Apparatus:* For investigating the cooling of a rotating end winding due to its own fanning action an experimental rotor was made as shown on Fig. 15.

The determination of the heat transfer constants from such a winding was subject to difficulties due to the irregular air flow through the windings. The irregularity was due to the unevenness of the coil separations also part of the coils, on the diamond portion, crossed each other forming a checker-board effect, while the remainder of the coil sides were parallel to each other. For these reasons tests were made on this model with self-ventilation only.

Tests and Discussion

The results of the tests obtained are shown on Fig. 16. The ventilation surface of the end coil was taken at its mean length of turn times the outside periphery. Tests were also made with the winding non-ventilated, that is, with the intake air cut off. The great differences shown by the two curves bring out clearly the importance of ventilating the winding. These two curves given for the insulated windings show a bending over of the curves with increasing speed due to the thermal drop through the insulation.

The similarity of the curves given for the ventilated

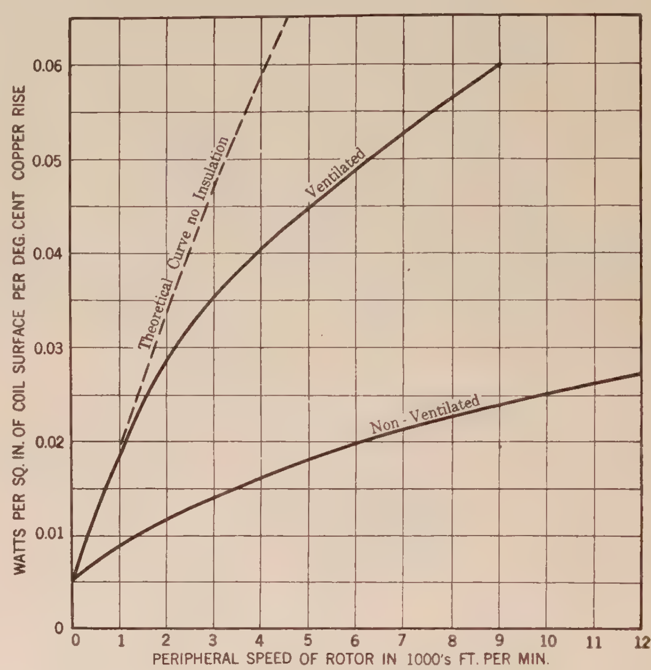

Fig. 16—Dissipation of Heat from Surfaces of Rotating End Windings

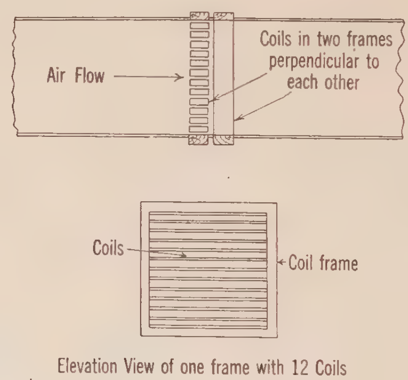

Fig. 17—Experimental Model for Testing the Heat Dissipation from End Windings

winding to that given on Fig. 13 for the heat transfer from a rotating cylinder in free air should be noted.

(b) *Test with Separate Ventilation.* In order to investigate more fully the ventilation of end windings, an experimental model was made as shown in Fig. 17. Two frames containing the sample coils were used. These could be arranged with the coils parallel and in line with each other, or by rotating one frame 90 deg. the coils in the two separate frames would cross each

other, forming the checker-board effect such as is formed on the diamond portion of the end windings.

Tests and Discussion

The results of these tests are shown on Fig. 18. The values given for the 1/8-in. and ¼-in. air spaces are a mean value for all the curves. This one curve is not only common for both of these ventilating spaces but is also common for both coil arrangements.

That is, the heat transfer coefficient is the same with the coil axes parallel and at right angles to each other. The values given for the 3/8-in. and ½-in. air spaces with the coils parallel lie below this mean curve while the values for these spacing with the coils at right angles are above the mean curve. It should be noted that the rate of increase of the heat transfer per 1000 foot air velocity is practically the same as that given for the laminated axial ducts, Fig. 9. The curves for the end windings do not pass through zero for zero air

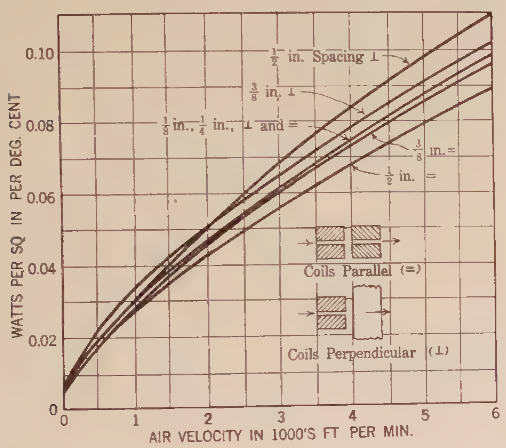

Fig. 18—Dissipation of Heat from End Windings by Forced Ventilation

velocity. This ordinate represents the heat dissipated by natural convection and radiation.

E. Dissipation of Heat from Cylindrical Surfaces

(*a*) *Plain Cylindrical Surfaces.* The current capacity of wires or cables either bare or insulated placed in a given air velocity stream will depend upon the rate of heat liberation from the ventilating surface. Tubular type of air coolers are also used for cooling the ventilating air in the closed circuit system of ventilation. Another application where heat is transferred from cylindrical surfaces is in the tubular type of air-oil coolers.

The transfer of heat from cylindrical surfaces with forced air convection at right angles to the cylinder axis is much greater than the coefficient previously given.

Hughes[10] tests on the heat transfer from the outside surfaces of copper tubes by forced air convections currents at right angles to the tubes are plotted on Fig. 24. These tests show a great variation of the constants with the tube diameter.

(*b*) *Cylindrical Surfaces with Fins.* In the tubular type of cooler or heat interchanger where a liquid is forced through the tube bore and the air flow is external at right angles to the tube, it will be found that the

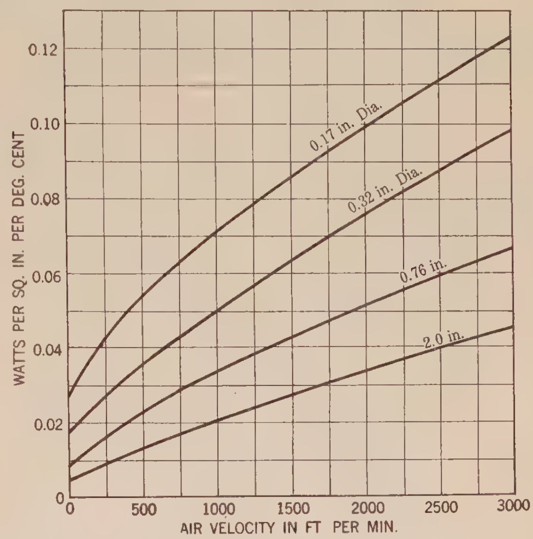

Fig. 19—Dissipation of Heat from the Outside Surface of Copper Tubes by Forced Air Convection at Right Angles to Tube

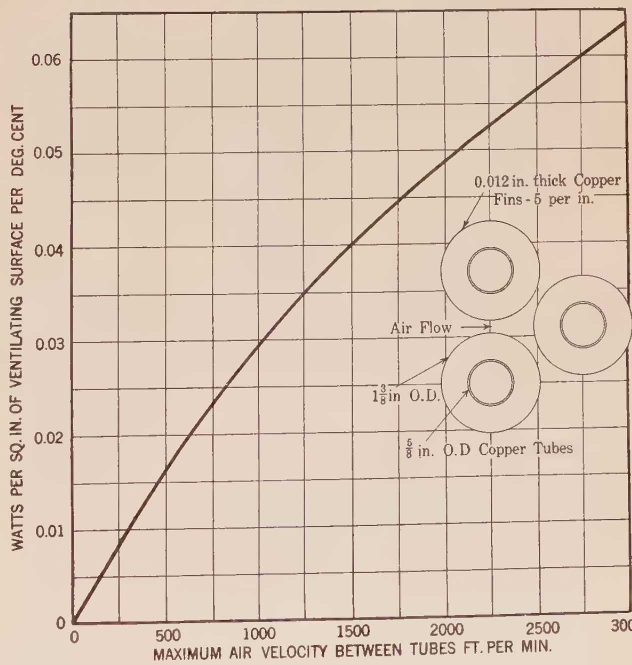

Fig. 20—Dissipation of Heat from Tubular Surfaces with External Fins by Forced Air Convection

limiting resistance to the heat flow will be on the air side, due to the high rate of heat transfer on the liquid side. Hence it is usually advisable to increase the effective air-ventilating surface by fastening metal fins on the outside of the tube. In this way the effective ventilating surfaces can be increased several fold.

Tests on such a cooler with 5/8 in. outside diameter copper tubes, equipped with 5 fins per inch of tube, are shown on Fig. 20. The heat transfer given is figured on the basis of the total ventilating surfaces composed of the outside tube surface and the total fin surfaces. The fin surface was six times the outside tubular surface yet the average heat transfer coefficient is much higher than that found with a uniform air flow through axial ducts.

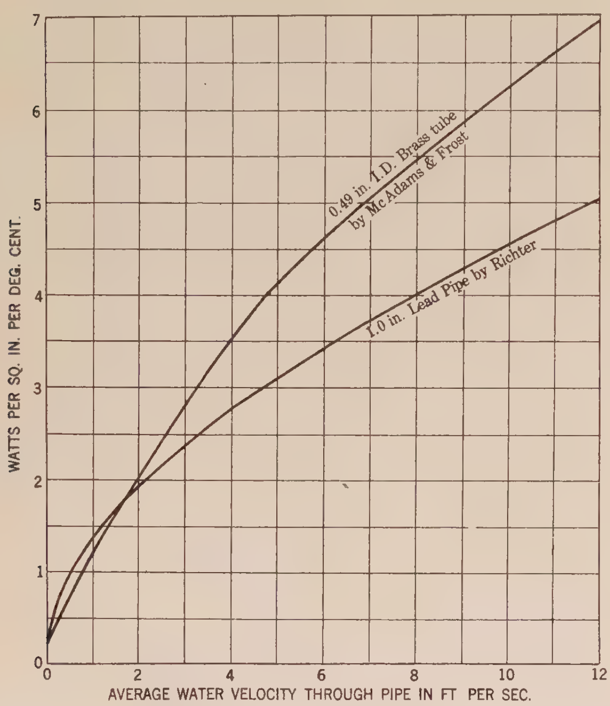

Fig. 21—Coefficient of Heat Transfer between a Metallic Surface and a Forced Water Stream

Dissipation of Heat by Liquids

A. Water. Some special motors and generators are cooled by forcing water through suitable pipes or ducts. Many oil-insulated transformers are also cooled by the same means. Water is especially adapted as an efficient cooling agent due to its high thermal capacity per unit volume and to the ease at which heat can be interchanged between it and the surrounding surfaces. The equation giving the relation between the water temperature rise, loss and water flow is approximately

$$T_w = \frac{0.00375\ W}{G}$$

where T_w = deg. cent. temperature rise of water.
W = watts loss absorbed by water.
G = gal. of water per minute (25 deg. cent.).

The heat transfer between a moving water column in a tube and the tube surface as found by Richter,[11] McAdams and Frost[12] is shown on Fig. 21. This rate of heat transfer is enormous compared to that obtained with air.

The values shown for zero water velocity are due to natural convection currents, these particular values vary considerably and in practise may be increased several times.

B. Oil. The use of oil as a "heat ferry" is quite common in transformers and bearings. The viscosity of oil is higher than that of water also its specific heat and coefficient of thermal conductivity are lower than the corresponding values for water. All of these factors have the effect of giving oil a lower rate of heat transfer than is obtained with water.

Data calculated from results obtained by Derby[13] on the rate of heat transfer with oil are shown on Fig. 22. The oil tested had a Saybolt viscosity of 50 seconds which is equivalent to common transformer oil at about 50 deg. cent. The heat transfer is shown to be considerably lower than those values given for water.

The equation connecting the oil temperature rise, rate of flow and watts loss absorbed for transformer oil at 50 deg. cent. is approximately

$$T_o = \frac{0.0095\ W}{G}$$

where T_o = deg. cent. oil temperature rise.
W = watts absorbed by the oil.
G = oil flow in gal. per min.

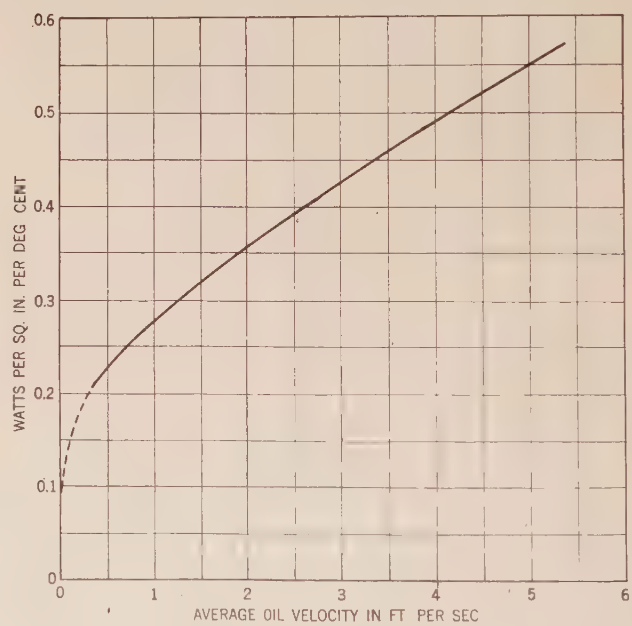

Fig. 22—Coefficient of Heat Transfer between a Metallic Surface and a Forced Oil Stream. Viscosity of Oil—50 Saybolt Sec.

The above data as given are by no means complete. The writer has attempted to give a summary of some of the principal factors to be considered in the cooling of electric apparatus, especially means for predetermining the rate of heat transfer from the heated surfaces. Problems encountered in the measurement of heat flow are especially difficult. No simple instruments of measurement are available such as are used for the

measurement of electrical energy. For this reason tests on the rate of heat transfer by separate experimenters may vary considerably due to different methods used.

The constants found for the cooling of a machine vary appreciably for different parts of the machine. Approximate results may be obtained by taking an average effective value of the cooling constant[14] and applying this to the total ventilating surfaces.

Bibliography

Note: The references are numbered as they appear in the paper.

3. The Transmission of Heat by Radiation and Convection by Ezer Griffiths and A. H. Davis. Special Report No. 9. Department of Scientific and Industrial Research, London, England. Published by His Majesty's Stationery Office.

4. Heat Dissipation. Reports of Westinghouse Elec. & Mfg. Co. Research Laboratory by T. S. Taylor.

5. Current Capacity of Wires and Cables by George E. Luke. *Electric Journal*, April 1923.

8. Longitudinal and Transverse Heat Flow in Slot-Wound Armature Coils by C. J. Fechheimer. A. I. E. E. 1921.

9. The Convection of Heat from Small Copper Wires by A. E. Kennelly, C. A. Wright and J. S. Van Bylevelt. A. I. E. E. 1909.

10. On the Cooling of Cylinders in a Stream of Air by J. A. Hughes and E. Coy. *Philosophical Magazine*, 1916.

11. Double Pipe Heat Interchangers by G. A. Richter, *Chem. & Met. Magazine*, March 24, 1920.

12. Heat Transfer by W. H. McAdams and T. H. Frost, *Journal of Ind. & Eng. Chem.* Jan. 1922.

13. Recooling of Lubricating Oil from Turbine Bearings and Gears by S. E. Derby. *Power Mag.* August 2, 1921.

14. Heating of Railway Motors in Serivce and on Test Floor Runs by G. E. Luke. A. I. E. E. 1922.

Discussion

C. J. Fechheimer: I think you have heard enough already to impress upon you the difficulties of the temperature problem, in electrical machinery; in fact, in any case where heat problems arise, we are confronted with difficulties such as the electrical engineer encounters perhaps in no other line of work. In fact, these difficulties are so great that for many years the electrical engineer would not spend much time on the consideration of how best the temperature should be computed. He simply passed it on and would say, "Oh, well, temperatures can't be figured anyhow; what's the use?" And I think nearly every electric designer has in the past met with results at times which came as complete surprises to him. It wasn't infrequent for him to find machines in test which heated, say, fifty per cent more or less than he estimated, and if in any other line of work the electric engineer couldn't calculate better than fifty per cent he would lose his job quickly.

These two papers are an index of the fact that we are going ahead; we are getting away from rule-of-thumb methods on the question of heating of electric machinery, getting them on a more scientific basis. It is high time that we are doing more; it is high time that a few devote their undivided attention to this very important problem.

I think perhaps one reason why the electrical engineer did not advance more rapidly in his study of the heating problem was because he tried to consider the subject as a whole. He took his final results from tests and endeavored to analyze them and found it was quite impossible. He got so many inconsistencies that he didn't know where he was. Now, the only way, after all, that we can make progress is by attacking the *elements* of a complicated problem. That is what the authors are doing. I know that in Mr. Luke's paper he has given the results of investigation on particular elements that go into the heating problem.

Especially in connection with the ventilation of machinery we are going ahead quite rapidly. We are realizing that there is a distinct connection, for instance, between the character of flow of water and that of air, and since we use air almost exclusively for cooling, we can take the results of the work of hydraulic engineers, or apply them directly to some of our problems in connection with the flow of air.

For the most part the engineer who has worked with air problems has considered air to be highly compressible whereas water is not, and therefore air could not be considered in the same manner as water. Now, as a matter of fact, the compression to which air is subjected in electric machinery is ordinarily of the order of one or two per cent or even less of the total pressure. Atmospheric pressure corresponds to approximately 407 inches of water, and it is seldom we run more than ten or twelve inches, which is less than three per cent.

Now, considering that very fact means that we can take the work of the hydraulic engineers and use their formulas for computation of such things as pressure drops in our machines, when they can be applied. We can use their method of attack in many cases and build up models of parts of machines and cause air to flow through them (or water, if it can be more readily used), and determine our constants, so we are better able to compute the air pressure drops as we can compute the electric pressure drops in our external networks, although, of course, the computation is far more difficult in the case of the air circuit than in the electric circuit. Then if we determine experimentally the characteristics of the generator of pressure, that is the fan, we have solved a very large part of the ventilating problem, if the air circuit is in an enclosed chamber such as in the high-speed turbine generators. Once we have determined how the air flows through the machine, and the volume and pressure, we have gone a long ways toward solving this very complex problem.

One more thing in connection with Mr. Rice's paper; electrical engineers have seldom used the method of dimensions for solving their problems. It is a method which is quite foreign to most of their methods of attack. I might suggest that they look into that a little further, but in using that method of dimensions great caution must be observed because some item might be overlooked and the solution will in consequence be entirely in error.

V. M. Montsinger: In Fig. 6 Mr. Luke gives some curves for the dissipation of total loss from large vertical plates. According to these curves and from 0 to 120 deg. cent. rise the loss varies approximately as the temperature rise raised to the powers of 1.3 and 1.36. For temperature rises used in practise I have found that the exponent is somewhat less than these values.

Suppose we consider rises from 20 to 70 deg. cent. and calculate the exponent considering both radiation and convection. If we differentiate the radiation formula we can calculate the exponential values for different values of rises for any given room temperature as follows:

$$k\,(T_2^4 - T_1^4) = (T_2 - T_1)^n\,k$$

$$\log\,(T_2^4 - T_1^4) + \log k = n \log\,(T_2 - T_1) + \log k$$

Differentiating, we get

$$n = \frac{4\,T_2^3}{(T_2 + T_1)\,(T_2^2 + T_1^2)}$$

The following gives the values of n for a room temperature of 20 deg. cent. ($T_1 = 293$ deg.)

$(T_2 - T_1)$	n
10	1.051
20	1.104
30	1.150
40	1.200
50	1.245
60	1.292
70	1.339
Average	1.197

Since approximately one-half the loss from a plain black surface is dissipated by convection and the other half by radiation and since the exponent is 1.25 for convection the general average exponential value should be about 1.225. This I find checks fairly closely with test results within this range of rises.

In second column on the fourth page, Mr. Luke gives a formula for the total loss from an irregular surface. For corrugated surfaces I have found that it is necessary to introduce a correction factor, say R, in the convection part of the formula to take care of restricted air circulation in deep corrugations. For instance, if we should have a corrugation 12 in. deep and with an air space 1 in. wide the value of R is about 0.5. In other words the convection is only about one-half as effective within this corrugation as for a plain surface. This reduction is a function of the width divided by the depth of the air space in the corrugation.

I hope to publish in the near future an article dealing with dissipation of loss by radiation and convection from plain and irregular surfaces and in which will be given a formula that will hold for any reasonable shape of corrugation, etc.

G. E. Luke: Mr. Montsinger has given some data indicating that the dissipation of heat from large vertical plates by radiation and convection should vary approximately as the temperature rise raised to the 1.225 power or $W = a\ T^{1.225}$ where (W) is watts loss per square inch of surface and (a) is a constant.

This equation is approximate for a given temperature range. The values of 1.30 to 1.36 given in the paper were averages for a temperature rise of 20 to 120 deg. cent. The exponents of (T) based on temperature rises of 20 to 70 deg. cent. would be reduced and would not differ materially from the above value given by Mr. Montsinger.

The exact value of this exponent is not well established, for example, Frank and Stephens[1] give data which result in a value of approximately 1.31 for this exponent based on a temperature rise up to 70 deg. cent. To determine the exact value of this equation will require exceedingly accurate tests and will probably be dependent upon the conditions of test such as size and position of plate and upon the natural air convection currents found in the room used for the tests.

There is no doubt but that the heat loss from a unit surface of a radiator or corrugated surface by natural convection will be less than that found from a plane surface so that a factor (R) as suggested by Mr. Montsinger would be desirable in the general heat loss equation from such surfaces. This constant will not only vary with the depth of the corrugations but will depend upon the height of the vertical surfaces and also upon the degree of freedom the air has in flowing through the radiator.

1. "Heat Dissipation from Self Cooled Oil Filled Transformers", by J. J. Frank and H. O. Stephens, A. I. E. E., 1911.

Free and Forced Convection of Heat in Gases and Liquids

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THE general problem of heat transfer requires a knowledge of the laws of conduction, radiation and convection. In 1822, Fourier gave us the first thoroughly scientific definition of conductivity and reduced the problem of heat conduction to an exact science, with a power and completeness which left little room for extension or improvement even to the present day. The law of radiation was first suggested by Stefan in 1879 as a result of an analysis of some experiments made by Tyndall. In 1884 Boltzman deduced the law theoretically from the principles of thermo-dynamics and electromagnetics. Thus the laws of conduction and radiation have been accurately known for a long time, while the problem of convection has received relatively little study. This fact is surprising when we consider the important part played by convection in almost all cases of heat transfer. A complete mathematical solution of a convection problem would require a knowledge of the hydrodynamic laws of viscous fluids for stream line and turbulent motion, combined with the Fourier equations of heat conduction in a moving medium. At present our lack of the hydrodynamic laws for turbulent motion renders a rigorous solution impossible. Therefore in most of the theoretical work so far attempted the simplifying assumption of an inviscid fluid has been found necessary. The theoretical results obtained when viscosity is neglected are in general far from the experimental facts. Langmuir's study of the problem showed that the viscosity is a factor of first importance which cannot be neglected. He therefore adopted a film theory as an approximation. The reason for the existence of a film around a hot body may be seen as follows: Consider a horizontal wire maintained at a given temperature in a fluid, the fluid adjacent to the wire will become heated and rise while the cooler fluid of greater density will flow into its place. Thus a convection current is set up by the difference in density between the hot and cold fluid. This condition is usually referred to as free convection. At the surface of the wire the fluid is stationary due to viscosity. As we proceed from the surface of the wire the velocity of

Abridgement of paper presented at the Annual Convention of the A. I. E. E., Swampscott, Mass., June 27, 1923. Complete paper available without charge to members on request.

the convection currents increase until a distance is reached at which the critical velocity conditions in the fluid are exceeded and the stream line flows bursts into turbulent motion. The discontinuity between the stream line and turbulent motion constitutes the outer boundary of the film. At the inner boundary the fluid has the temperature of the hot surface and at the outer boundary the temperature of the ambient fluid. The actual configuration of the outer boundary is unknown. As an approximation we might assume that it was an eccentric ellipse or cylinder, etc., and determine the size and eccentricity so as to best fit the experimental results. For ease of calculation Langmuir adopted the simplest approximation and assumed that the outer boundary of the relatively stagnant film was a cylinder concentric with the wire. He thus reduced the hopelessly complex problem of convection to one of conduction in the steady state.

The question of how the film thickness varies with the size and shape of the body and properties of the ambient fluid is determined by the method of dimensions plus experiments. Raleigh has frequently pointed out the great power of the *method of dimensions* in obtaining the solution of physical problems. He says—"It often happens that simple reasoning founded upon this principle tells us nearly all that is to be learned from even a successful mathematical investigation, and in numerous cases where such a mathematical investigation is beyond our powers, the principle gives us information of the utmost importance." As already stated the problem of convection is at present beyond our reach and therefore we have to be content with the information which we can obtain from the *method of dimensions.*

Recently Davis has attacked the problem by dimensional methods starting from certain general hydrodynamic considerations which do not take into consideration the existence of a film. In the present papers on Free and Forced Convection Langmuir's film theory has been extended by dimensional analysis and it is felt that the results obtained give a clearer insight into the mechanism of convection, as well as more useful equations. An attempt has also been made to bring together the available data and correlate them as far as possible. A striking example of the practical results which may be expected from a thorough understanding of the laws of conduction, radiation and convection is found in Langmuir's gas filled lamps. His study and application of these laws allowed him to more than double the efficiency of the incandescent lamp.

Discussion

V. M. Montsinger: I think I am safe in making the statement that there is no other problem which offers any more difficulties than does that of heating and cooling. This is especially so in investigating free convection. In fact there are usually so many factors to be taken into consideration that it is practically impossible to arrive at any simple rule or formula that will hold for all the conditions met with in practise. I think one of the most important points to be considered in deriving a formula for free convection is that of the size of the area, that is, whether the heated surface is concentrated in a small area or whether it covers a large area several feet in height. Mr. Rice has considered this within a certain range of sizes. Another important point is the range in temperature used.

As most of the data used by Mr. Rice were obtained either from relatively small areas or at fairly high temperatures, that is, above 100 deg. cent. rise and as a contributing part to this compendium, I would like therefore to give in brief some of the results of my experience covering a period of several years in cooling mostly by free convection, of large areas at relatively low temperature rises, less than 100 deg. cent. rise. This lower region of temperature rise is a very important one from a practical standpoint for the reason that the limiting temperature of all class A insulating materials used so extensively in electrical apparatus comes within this range.

First, in reference to the question of the film of inactive air next to the heated surface I think perhaps it may be of interest if I give in a very general way the results of a recently conducted experimental observation which confirms very conclusively the existence of a film of apparently stationary gas on the heated surface.

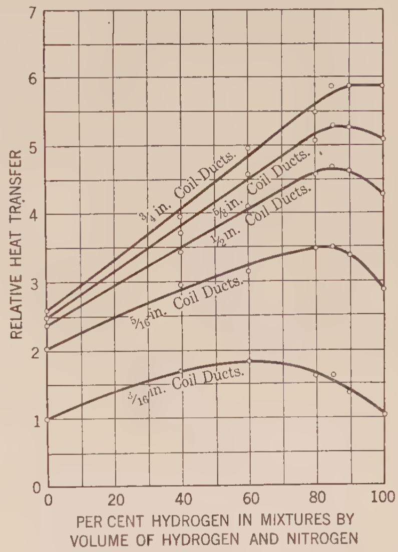

Fig. 1—Curves showing Effect of Size of Coil Ducts on Cooling of Vertical Coils by Free Convection in Gases at 200 Lb. (als.) Pressure

The experiment consisted in cooling by free convection a series of vertical transformer coils separated by various ducts of different sizes in, (1), a light gas of hydrogen, (2), in a heavy gas of nitrogen and (3), in a mixture of the two gases.

For the larger sizes of coil ducts used around ½ in. to ¾ in., the relative heat transfer or convected losses for a given temperature rise for the two gases checked fairly closely the values calculated by Mr. Rice's formula in which the loss varies directly with the product of heat conductively and the square root of the gas density and inversely with the square root of the viscosity.

But for the smallest coil duct used around $^3/_{16}$ in., it was found that there was practically no difference in the cooling by either of the gases when under 200 pounds absolute pressure. What appeared at first to be somewhat puzzling occurred when mixtures of these gases were used varying from 100 per cent nitrogen to 100 per cent hydrogen by volume. For instance, with a 50-50 mixture, the loss dissipated for a given rise was

approximately 50 per cent greater than for either of the pure gases, and this difference in cooling with the pure gases and their mixtures gradually decreased as the mixture approached either one of the pure gases.

This hump in the efficiency curve gradually disappeared (as the coils with larger ducts were used) by moving over in the direction of the ¾ in. ducts and, of course, as the ducts became larger the cooling became better and better for the hydrogen gas, as compared with nitrogen. This is illustrated in Fig. 1.

The important point however is this: what was the cause of it? According to Mr. Rice's formula, nitrogen has a thin film of inactive gas on the surface and hydrogen gas has a relatively thick film—about 2.6 times greater than that of nitrogen at 50 deg. cent. and at 200 pounds pressure. Naturally then for small constricted paths the thick hydrogen film was clogging the circulation whereas the thin film of nitrogen allowed a much more free circulation and it so happened for this particular size of duct that the cooling was about equal, whereas for unrestricted circulation the cooling of hydrogen ranges from 2 to 3 times as great as that of the nitrogen.

Beginning with hydrogen as the cooling medium and as nitrogen was gradually added, thus forming a mixture, the gain due to decreasing the film thickness was up to a certain point more than the loss due to the addition of the poor cooling gas (and consequently loss of equal amount of hydrogen) but finally at approximately 50-50 mixture the conditions of gain and loss reversed themselves and the cooling again decreased. This phenomena proves conclusively the existence of a gas film upon which Mr. Rice's formulas are based.

Second, in reference to the question of the variation of free convection loss with temperature rise as given by Mr. Rice's equation (**126**), I wish to make the following comments: if we choose some definite ambient temperature, say 30 deg. cent., the equation expresses the loss as a function of the average of the absolute temperatures of the heated surface and ambient raised to the 0.754 power multiplied by the temperature difference in degrees cent. If we calculate the loss by this equation and plot loss as ordinates and temperature rise as abscissa on double-log paper we find that the loss varies up to 100 deg. almost exactly as the temperature railed to the 1.06 power. But as Mr. Rice states in the paper from 100 to 500 deg. the average exponential value is around 1.25. For example the following tabulation gives the values of the exponent between each 100 deg. rise up to 500 deg. cent. as calculated from his formula.

For temperature rise Between limits of:	Loss varies approx. as temperature rise raised to power of:
0–100 deg. cent.	1.06
100–200 deg. cent.	1.14
200–300 deg. cent.	1.24
300–400 deg. cent.	1.265
400–500 deg. cent.	1.37

Average from 100 to 500 deg. cent. = 1.254.

However, I have found as I pointed out in my article in June 1916 proceedings that the exponent of 1.25 holds from 0 to 100 deg. and I am quite certain that loss by convection for large areas does not vary even approximately as the first power of the temperature rise as given by equation (**126**).

I have been using for over ten years this value of the exponent, namely 1.25, in connection with the cooling of large selfcooled transformers having tanks with irregular surface where the greater part of the heat is dissipated by convection and I find that it always checks very closely with the test results. The difference between the loss calculated on the basis of using an exponent of 1.06 and one of 1.25 is quite an appreciable amount. For instance, if the constant is so chosen that the lines cross at 10 deg. rise the difference in loss at 100 deg. rise is in the ratio of about 1 to 1.5.

To obtain laboratory accuracy on the loss of heat by free convection from rather tall vertical surfaces I recently made a series of tests on a cast iron plate about 3.15 in long by 13.1 in. wide by $1^1/_{16}$ in. in thickness. In the plate were imbedded sheath wire units of equal resistance about 2 in. apart so as to obtain a uniform temperature throughout the whole area including both sides of the plate. This eliminated the necessity of making corrections for stray losses in case one side of the plate had been blanketed, as is sometimes done in investigations of this kind.

The plate was suspended in a vertical position in the air in an open room having a constant temperature. Fifteen thermocouples were soldered in holes in the surface on one side and five on the other side of the plate, the five being used merely as a check to see if both sides were at the same temperature. Direct current was used to supply the loss. All readings of volts and amperes and thermocouples were taken with a potentiometer. For convection, the air was used as the ambient. For radiation the temperature of the walls of the room about 10 feet distance was used for the ambient although the air and wall temperatures were usually the same.

Three series of runs were made with both sides of the hot plate under the same conditions, namely:

(1) painted a lamp black; (2) nickel plated and polished, and (3) with the surfaces partly oxidized and set permanently at about 325 deg. cent. before making any test.

For the first condition the paint began to scale off when the temperature reached approximately 100 deg. cent. or about

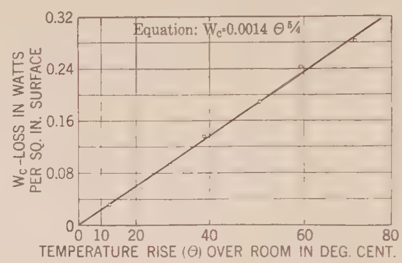

Fig. 2—Heat Loss by Free Convection from Plane 31.5″ Height and 13.1″ Width, Painted Lamp Black

72 deg. rise and the test had to be discontinued. Up to this point the loss by convection was taken as the difference between the total loss and the loss calculated by the standard radiation law and assuming that the emissivity factor was 0.9 that of a perfect black body. The radiation constant used was 3.68×10^{-11}

The convection loss points fell on a straight line on double-log paper the equation of the line being

$$W_c = 1.40 \times 10^{-3}\,\theta^{1.265} \tag{1}$$

in which W_c is the watts per square inch of surface and θ is the temperature rise in deg. cent. The loss is plotted against temperature rise raised to the 5/4 power in Fig. 2.

For the other two conditions of the plate surface the emissivity factor for radiation was assumed to be that obtained by subtracting from the total loss for a given rise around 50 or 60 deg. cent. the convection loss according to equation (**1**). The resulting value of emissivity was used throughout the range of test temperatures in determining the convection loss points.

According to the above method of procedure the emissivity factor for the nickel plated and polished surface was 0.07.

Up to about 150 deg. cent. rise the convection loss points fell in a straight line on double-log paper, the slope of the line being about 1.26. From 150 to 300 rise the points gradually drew away from the straight line and at 300 deg. rise the loss was about 25 per cent higher than the straight line. Fig. 3 shows the loss plotted against temperature rise raised to 5/4 power.

At first it was thought that this departure from a straight line on double-log paper was due to a change in the law but

(as will be seen later where tests were made with the surfaces partly oxidized did not show this departure), it was apparently due to a gradual oxidation of the surface which at first was not discernable to the eye but which gradually increased the emissivity factor. At about 300 deg. rise the surface became so tarnished that the tests were discontinued.

For the last set of tests the surfaces were painted black and then subjected to a temperature of 325 deg. cent., for about a day, so as to let it get "set" before making any test. Some of the paint came off and what remained turned a brownish color.

Tests were taken first with the temperature decreasing and

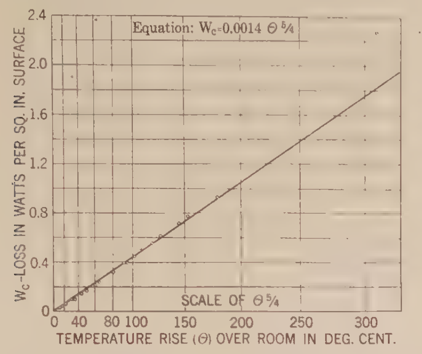

Fig. 3—Heat Loss by Free Convection from Vertical Plane 31.5 in. Height and 13.1 in. Width. Nickel Plated and Polished

second with an increasing temperature. The emissivity factor, determined as described before, was 0.52. The convection loss where plotted vs. temperature rise on double-log paper fell practically on a straight line up to 280 deg. cent. rise—as far as the temperature was taken—with a slope of the line of 1.25. This is shown in Fig. 4.

As stated before, the results above approximately 100 deg. rise agree fairly well with Mr. Rice's formula and I do not think that because they disagree below 100 deg. rise they contradict the film theory. As I stated in the beginning of the discussion the conditions of cooling a large plate are so radically different

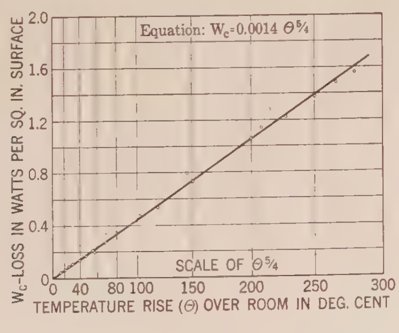

Fig. 4—Heat Loss by Free Convection from Vertical Plane 31.5 in. Height and 13.1 in. Width. Surfaces Partly Oxidized before Tests

from that of cooling a small area where the heat is concentrated and especially at low temperature differences that possibly the same equations would not be expected to hold for both conditions.

The point which I wish to emphasize is that for a large vertical surface and for temperature rises used in most electrical apparatus the loss can be expressed close enough for practical purposes by a simple exponential equation in which the loss varies as the 5/4 power of the temperature rise. This agrees with the results found by Messrs. Ezer, Griffiths and A. H. Davis conducted under the auspices of the Department of Scientific and Industrial Research, and shown in their Special Report No. 9 issued last year on "The Transmission of Heat by Radiation and Convection." This was for temperature rises up to 100 deg. cent. and for vertical planes up to approximately 35 in. in height. For heights of 69 and 104 in. the values of the exponent were 1.3 and 1.34 respectively. The constant in their formula was the same (1.28×10^3) for all heights above 12 in. (30 cm.). For smaller heights than 12 in. they found that the constant increased. The constant I found from the tests on the hot plate was 1.4×10^3 or about 9 per cent higher than Griffiths and Davis' value, for corresponding heights.

Chester W. Rice: In the above discussion Mr. Montsinger called my attention to the fact that the free convection from vertical plane surfaces varies as the 5/4 power of the temperature difference whereas my equations make the convection vary approximately as the first power of the temperature rise for small temperature differences. In view of this lack of agreement between the theory and experiment for low temperature differences, it seemed desirable to reexamine the available data on the basis of a more general expression for the film thickness so as to obtain, if possible, a single expression which would be inversely application for both large and small temperature differences. In a subsequent paper it will be shown that the desired universal expression can be readily found and that it leads to the following conclusions.

(1). The more general expression for the effective film thickness, here developed, is seen to be superior to the simpler expression of the previous paper since the resulting equations account accurately for the convection from large and small bodies at both high and low temperature differences.

(2) The general expression for the effective film thickness obtained by the method of dimensions for free convection is

$$B = K\, D\, (k/\mu\, c_p)^p\, [\nu/(\alpha\, g\, \Delta\, t)^{1/2}\, D^{3/2}]^n \quad \text{cm.} \quad (1)$$

where K = Experimental constant depending on the system of similar bodies under consideration
D = Characteristic linear dimension of body in cm.
k = Heat conductivity at average temperature watt cm.$^{-1}$ deg. cent.$^{-1}$
μ = Viscosity of fluid at average temperature cm.$^{-1}$ gram sec.$^{-1}$
C_p = Specific heat at constant pressure for average temperature Joule gram^{-1} deg. cent.$^{-1}$
p = Experimental exponent
ν = μ/ρ = Kinematic viscosity of fluid for average temperature cm.^{2} sec.$^{-1}$
α = Coef. of density change per deg. cent. for average temperature in deg. cent.$^{-1}$, for ideal gases $\alpha = 1/273$
g = Acceleration of gravity = 980 cm. sec.^{2}
$\Delta\, t$ = Difference between surface and ambient temperature deg. cent.
n = Experimental exponent for the system of similar bodies under consideration.

(3) When dealing with *ideal gases,* the first factor in equation (1) can be neglected since it does not vary greatly from one gas to another. Under these conditions we write the effective film thickness

$$B = K_1\, D\, [\nu/(\alpha\, g\, \Delta\, t)^{1/2}\, D^{3/2}]^n \quad \text{cm.} \quad (2)$$

(4) The free convection from *long horizontal cylinders* in *gases* and *liquids* is given by

$$W_c = 2\,\pi\, L\, \Delta\, \varphi/\log_\epsilon [\,(2\,B + D)/D] \quad \text{watt} \quad (3)$$

where L = Length of cylinder in cm.
$\Delta\, \varphi$ = Thermal conduction in watts per cm.
D = Diameter of cylinder in cm.
B = Film thickness in cm. from Eq. (1).

A sufficiently close approximation is usually obtained by taking $n = 1/2$; $K = 2.12$ and $p = 1/4$ in equation (1).

(5) The free convection from *long vertical cylinders* in *gases* is given by equation (3) and the film thickness by equation (2). The meager available data give $n = 2/3$ and $K_1 = 8.65$.

(6) The free convection from *spheres* in *gases* is given by

$$W_c = 2\pi \Delta \varphi / [1/D - 1/(2B + D)] \quad \text{watts} \quad (4)$$

and the film thickness by equation (2) in which $n = 1/2$ and $K_1 = 2.02$.

(7) For *large surfaces* the film thickness will usually be small compared with the film thickness and the shape conductance will then take the simple form $S = A/B$. For moderate temperature differences we may also take $\Delta \varphi = k_{avg.} \Delta t$. Under these conditions, our general expression for free convection becomes

$$W_c = (A\, k\, \Delta t / K\, D)\, (\mu\, c_p/k)^p\, [\, (\alpha\, g\, \Delta t)^{1/2}\, D^{3/2}/\nu]^n \quad \text{watts} \quad (5)$$

For *ideal gases* we may omit the first factor without great error and obtain

$$W_c = (A\, k\, \Delta t / K_1\, D)\, [\, (\alpha\, g\, \Delta t)^{1/2}\, D^{3/2}/\nu]^n \quad \text{watt} \quad (6)$$

(8) For *large long horizontal cylinders* in *gases* and *liquids* we take $K = 2.12$; $n = 1/2$ and $p = 1/4$ in equation (5). For the convection in *air* we obtain

$$W_c = 0.000785\, A\, (1/D)^{1/4}\, p^{1/2}\, (1/T_{avg.})^{.123}\, \Delta t^{5/4} \quad \text{watt} \quad (7)$$

where $A = \pi D L$ = Area in square cm.
D = Cyl. diam. in cm.
L = Length of long cylinder in cm.
p = Air pressure in atmosphere
$T_{avg.}$ = Average of cyl. and amb. absolute temperature deg. K
Δt = Temperature difference deg. cent.

(9) For *large long vertical cylinders* in *gases*, we take $n = 2/3$ and $K_1 = 8.65$ in equation (6). For *air* we obtain the following approximation

$$W_c = 0.00166\, A\, p^{2/3}\, (1/T_{avg.})^{.415}\, \Delta t^{4/3} \quad \text{watt} \quad (8)$$

(10) For *large spheres* in *gases* we take $n = 1/2$ and $K_1 = 2.0$ in equation (6). For *air* we then obtain the following approximation.

$$W_c = 0.00088\, A\, (1/D)^{1/4}\, p^{1/2}\, (1/T_{avg.})^{.123}\, \Delta t^{5/4} \quad \text{watt} \quad (9)$$

(11) For a *long thin vertical plane* surface (ribbon surface) in *gases* we may take as an approximation $n = 1/2$ and $K_1 = 1.46$ in equation (6). We also take D equal to the vertical height H in cm. For *air* we then obtain

$$W_c = 0.00121\, A\, (1/H)^{1/4}\, p^{1/2}\, (1/T_{avg.})^{.123}\, \Delta t^{5/4} \quad \text{watt} \quad (10)$$

(12) The more general theory of the present paper shows that *free convection* tests *can not be used* as a *primary method* of *obtaining heat conductivities.* The method, however, is still of interest where an approximation value of the heat conductivity already exists. Below, the heat conductivities have been recalculated by this method.

No. 12 Transil Oil	$= 0.0017\,(1 - 0.0026\, t)$	watt cm.$^{-1}$	deg.cent.$^{-1}$		
Toluene	$= 0.0015\,(1 - 0.0029\, t)$	"	"	"	
Glycerine	$= 0.0033\,(1 - 0.0038\, t)$	"	"	"	
Aniline	$= 0.0020\,(1 - 0.0018\, t)$	"	"	"	
CCl_4	$= 0.0012\,(1 - 0.0038\, t)$	"	"	"	
Olive Oil	$= 0.0016\,(1 + 0.0055\, t)$	"	"	"	

The value for olive oil should not be given much weight due to the large uncertainty concerning the viscosity. The present method gives, excepting olive oil, negative temperature coefficients whereas, the method of the previous paper gave positive values.

An oversight was made in Section V under *Effect of Ambient Temperature.* Here the experiments were tested by calculating the film thickness for the high and low ambient temperatures from the observed convection. These calculations showed that the film thickness increased with increasing ambient temperature as was required by the theory and therefore the agreement was considered satisfactory. Now the heat conductivity increases with the temperature, but not quite as fast as the film thickness increases and therefore the convection per degree cent. should decrease with increasing ambient temperature, whereas the experiments show an increased convection per deg. cent. for the high ambient temperature. Thus the *oven tests* are contrary to the theory of the paper as well as the more general theory outlined above. It is probable that convection currents were the cause of the trouble.

In Section VII of the paper, we used Compan's data on free convection from spheres to determine the constants in the convection laws. In the course of the recent work, I have re-examined Compan's data and compared it with the work of Pelet (*Traité de la Chaleur*, Third Edition, Vol. 111, pp. 418-481) and M'Farlane (*Proc.* Royal Soc. London, Vol. 20, p. 90, 1871 and 1872) with the result that Compan's experiments do not agree at all with the others. It seems probable that the trouble with Compan's work is due to the use of a small sphere covered with a thick coat of lamp black. In the above summary of the recent work Compan's data have therefore been neglected. His data on forced convection have likewise been neglected in the following discussion on forced convection.

A recent study of a fund of valuable data on the heat transfer to liquids flowing in pipes, which has come to the writer's attention, showed that here also a more general expression for the film thickness is necessary to properly correlate the heat transfer in liquids with that in gases. In a subsequent paper the new data will be presented and the following conclusions reached.

(1) The more general expression for the effective film thickness, here developed, is superior to the expression of the previous paper in that it allows us to correlate the heat transfer in gases and liquids.

(2) The general expression for the effective film thickness obtained by the method of dimensions is

$$B = K_0\, D\, (k/\mu\, C_p)^p\, (\mu/\rho\, D\, v)^x \quad \text{cm.} \quad (11)$$

where K_0 = Experimental constant depending on the system of similar bodies under consideration
D = Characteristic linear dimension of body in cm.
k = Heat conductivity at average temperature watt cm.$^{-1}$ deg. cent.$^{-1}$
μ = Viscosity of fluid at average temperature cm.$^{-1}$ gram sec.$^{-1}$
C_p = Specific heat at constant pressure for average temperature Joule gram^{-1} deg. cent^{-1}
p = Experimental exponent
ρ = Density of fluid at average temperature gram cm.$^{-3}$
v = Mean velocity of fluid relative to the surface cm. sec.$^{-1}$
x = Experimental exponent

(3) When dealing with *ideal gases* the first factor in equation (11) can be neglected since it does not vary greatly from one gas to another. Under these conditions we obtain

$$B = K\, D\, (\mu/\rho\, D\, v)^x \quad \text{cm.} \quad (12)$$

which is the expression assumed for both gases and liquids in the previous paper.

(4) For thin films and moderate temperature differences we obtain for *gases* and *liquids.*

$$W_c = (A\, k\, \Delta t / k_0\, D)\, (\mu\, C_p/k)^p\, (\rho\, D\, v/\mu)^x \quad \text{watt} \quad (13)$$

where A = Area of surface cm.^{2}
Δt = Temperature difference deg. cent.

(5) For *ideal gases* the factor $(\mu\, C_p/k)^p$ may be neglected with sufficient approximation so that

$$W_c = (A\, k\, \Delta t / K\, D)\, (\rho\, D\, v/\mu)^x \quad \text{watt} \quad (14)$$

This relation was tested over a wide range of conditions in different gases in the previous paper with good agreement.

(6) For *smooth pipes* well above the critical velocity, the available data in *gases* and *liquids* is approximately satisfied by taking $p = 1/2$, $x = 5/6$ and $K_0 = 60$ in equation (13).

(7) The film theory naturally suggests a relation between the mechanical resistance to flow and the heat transfer. A study of the heat transfer and mechanical resistance for pipes leads to the following relation:

$$W_c = (A\, k\, \Delta t\, R/v\, \mu)\, (\mu\, C_p/k)^p \quad \text{watt} \quad (15)$$

where R = mechanical resistance dynes cm.$^{-2}$

(8) We may write equation (**15**) in the following form

$$W_c = (A\ C_p\ \Delta\ t\ R/v)\ (k/\mu\ C_p)^{1-p} \qquad \text{watt} \quad (\mathbf{16})$$

which is seen to conform to Reynolds Law as given by Stanton.

(9) If we substitute Lees equation for the resistance to flow in *smooth pipes* in equation (**16**), and assume $p = 1/2$ we obtain for *gasea* and *liquids.*

$$W_c = (k/\mu\ C_p)^{1/2}\ A\ \rho\ C_p\ v\ \Delta\ t\ [0.0009 + 0.0763/(v\ D\ \rho/\mu)^{.35}] \qquad \text{watt} \quad (\mathbf{17})$$

This equation takes into account the variation of the resistance with the degree of turbulence and therefore should be applicable over the entire range above the critical velocity.

For *ideal gases* we may take with sufficient approximation

$$W_c = 1.16\ A\ \rho\ C_p\ v\ \Delta\ t\ [0.0009 + 0.0763/(v\ D\ \rho/\mu)^{.35}] \qquad \text{watt} \quad (\mathbf{18})$$

For *air* equation (**18**) becomes approximately

$$W_c = (0.417\ A\ p\ v\ \Delta\ t/T_{avg.})\ [0.0009 + 0.0012\ T_{avg.}^{.615}/(v\ D\ p)^{.35}] \ \text{watt}\ (\mathbf{19})$$

where p = absolute air pressure in atmospheres

$T_{avg.}$ = Average of surface and ambient absolute temperature

(10) For *rough pipes* (fine sand paper) we will assume $x = 1$, $p = 1/2$ and $K_0 = 136$ in equation (**13**).

For *ideal gases* we then obtain

$$\overline{W}_c = 0.00635\ A\ \rho\ v\ k\ \Delta\ t/\mu \qquad \text{watt} \quad (\mathbf{20})$$

For *air* we have

$$W_c = 0.0031\ A\ p\ v\ \Delta\ t/T_{avg.} \qquad \text{watt} \quad (\mathbf{21})$$

(11) For cylinders in *ideal gases* the values obtained in the previous paper still hold. We therefore take $x = 1/2$ and $K = 2.2$ in equation (**14**) and obtain for thin films

$$W_c = (A\ k\ \Delta\ t/2.2\ D)\ (\rho\ D\ v/\mu)^{1/2} \qquad \text{watt} \quad (\mathbf{22})$$

where D = Diameter of cylinder in cm.

For *air* we obtain

$$W_c = 0.0018\ L\ \sqrt{p\ D\ v}\ \Delta\ t/T_{avg.}^{.123} \qquad \text{watt} \quad (\mathbf{23})$$

where = Length of cylinder in cm.

(12) The heat transfer in gaseous mixtures are covered by the general equations which apply to liquids and gases.

Artificial Transmission Lines With Distributed Constants

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Member, A. I. E. E.

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THE theory of the transmission of electricity has been materially advanced through the use of artificial transmission lines in the laboratory.

Artificial lines of various types have been in use for about thirty years, one of the first investigations being in connection with submarine signaling and later Pupin developed artificial equivalents in connection with his work upon loaded telephone lines. At the present time these artificial equivalents are used extensively in telephone and telegraph work for balancing circuits, or as standards of transmission distance, while a large number are used for educational purposes in the laboratories of engineering schools. In a few cases power companies have built equivalents of a portion of their system for investigations of the power distribution.

The usual construction involves the use of lumped constants, or in other words, a coil having the desired values of resistance and inductance is connected in the proper manner to one or more condensers of the correct value of capacity, the group being equivalent to a section of line of definite length. These units may be connected in either star or delta combinations, and are usually referred to as a T or π section. If the equivalent section of line is short the values of the total inductance, capacity and resistance per section in the actual line and its artificial equivalent may be made identical without introducing more than a negligible error. If the equivalent section is long, however, correction factors must be used.

While this type of construction is in many ways satisfactory and useful it has certain very definite limitations which prevent the experimental development of transmission theory along certain lines. At present the most important of these is the investigation of transient phenomena. The lumpy type of line loses its equivalence to the actual line when the flow of current is not a repeating function, since the constants behave as separate units towards the wave fronts set up in changing from one state of flow to another, resulting in very large reflections from the inductance lump and very large conduction by the capacity lump. If the inductance were entirely free from distributed capacity then a vertical wave front would be completely reflected. However, the inductance coil must always contain a certain amount of distributed capacity and therefore the reflection of a wave front will depend upon the ratio of the inductance to the distributed capacity that actually exists.

Development of the Artificial Line with Distributed Constants

This type of line is referred to as a "smooth" line in distinction from the more usual lumpy line. From time to time attempts have been made to produce such a smooth line for the study of transient or other conditions. Taylor & Muirhead, Pupin and Union College were all successful in doing this to a certain extent.

The Research Division of the Electrical Engineering Department of the Massachusetts Institute of Technology started an investigation of the possibilities of making a satisfactory smooth artificial line in the fall of 1920. The work has been done largely by graduate students and research assistants. Mr. L. H. Becker began the first attempts at making coils with distributed

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constants, and the first tests were carried out by Messrs. M. F. Gardner and E. J. Arnold, all of these being research assistants. The design of the single-phase line was carried out by the author, and the more extensive tests, which are to be described in another paper, were carried out by Messrs. Scott, Van Ness and Jackson, graduate students, under the supervision of Mr. S. M. Jones, research assistant. The design of the three-phase line was done as a graduate thesis by Messrs. P. T. Coffin and L. O. Buckner, and the test work upon this line is now under way by a group of graduate

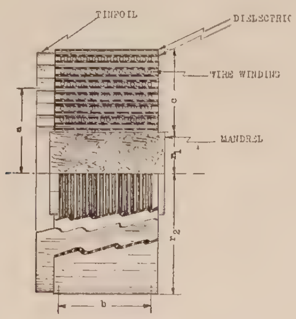

Fig. 1—Cross-Section of Round Wire Type of Smooth Artificial Line Coil

The arrangement with rectangular wire is the same, but usually somewhat longer compared to the diameter.

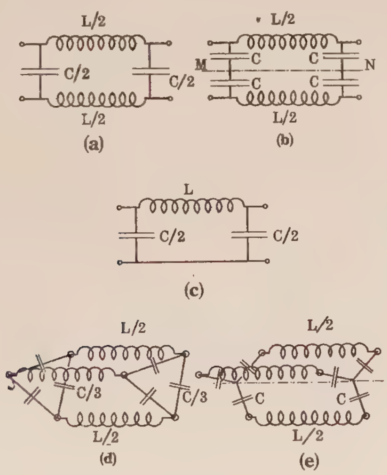

Fig. 2

(a) Circuit Equivalent of a Single-Phase Transmission Line,

(b) The Same Circuit as (a) Broken up to Show Two Wire-mile Equivalent Sections Combined to Represent the Line

(c) The Same Section Length as (b) with the Constants Lumped to Give a Loop-Mile Section

(d) A Three-phase Transmission Line Represented by Lumped Constants

(e) The Same Circuit as (d) with the Capacities Connected in Star Instead of Delta

(The values of the constants in all the different sections are marked to show the values giving the same nominal length of section for each type of circuit). It will be noted that (e) is the same as three of the wire-mile sections used in (b).

students. After considerable experimenting it was decided to develop the Pupin type of coil. The final type of construction consists of a multilayer coil wound with bare, or enamel insulated, copper wire of rectangular or circular cross section. Between each layer of winding, and also on the inside and outside of the coil, is wound a layer of tinfoil, insulated from the conductor by impregnated condenser paper. Each layer of tinfoil projects at one end so that all the layers may be soldered together. There must also be a break in each layer along the same radial line, so that the tinfoil does not make a short-circuited secondary for the main winding. This results in a coil having the capacity uniformly distributed with respect to the conductor. The leakage is also uniformly distributed, but there is a certain periodicity of constants due to the existence of mutual inductance between turns in each coil. This does not appear to interfere with its equivalence to an actual line, as shown from tests made upon the lines. One important facility contributing largely to the success of this construction is the availability of three electrode vacuum tube amplifiers for use in making tests. The operation of the usual type of metering equipment and oscillographs requires so much power that if they are directly connected to the line the

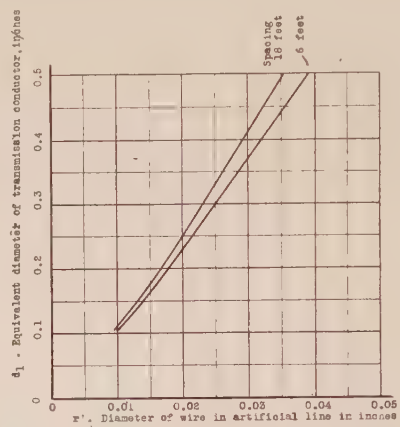

Fig. 3—Curve Showing the Relations Between the Diameter of Wire Wound in the Smooth Artificial Line Coil and the Equivalent Diameter of Transmission Line Conductor Represented

The upper curve is for a wire spacing of 18 ft. (5.5 m.) and the bottom curve is for a spacing of 6 ft. (1.83 m.). The equivalent length of section varies from 2 to 40 miles (3.2—64 km.), increasing with the diameter of wire in coil. The length of wire in the coil varies from 5000 to 50,000 cm. (164-1,640 ft.), also increasing with the diameter of wire. The design constants were taken as follows:

$K = 2.5 \qquad y = 1.5 \qquad H = 0.6 \times 10^{-3} \qquad \delta = 0.0025$ in.

resultant equivalent load is very large and distorts the line condition seriously. Such equipment can only be connected to the end of the line which is attached to the power supply without introducing serious errors.

Owing to the interdependence of the various constants in the coil the design is somewhat complicated. A change in any one dimension affects all the other constants and cut-and-try methods are very laborious and wasteful. Therefore a method of design has been worked out which will give reasonably accurate results.

It introduces of necessity several design constants which have to be more closely determined by a sample coil, but usually one or two samples will suffice to predict the results within five to ten per cent, which is as close as coils of this sort can be manufactured com-

mercially. If greater accuracy is necessary the coils must be wound slightly oversize and then unwound until they fit the required constants. Since the capacity reduces directly with the first power, and the inductance approximately proportionately to the square of the turns unwound, it is always possible to unwind

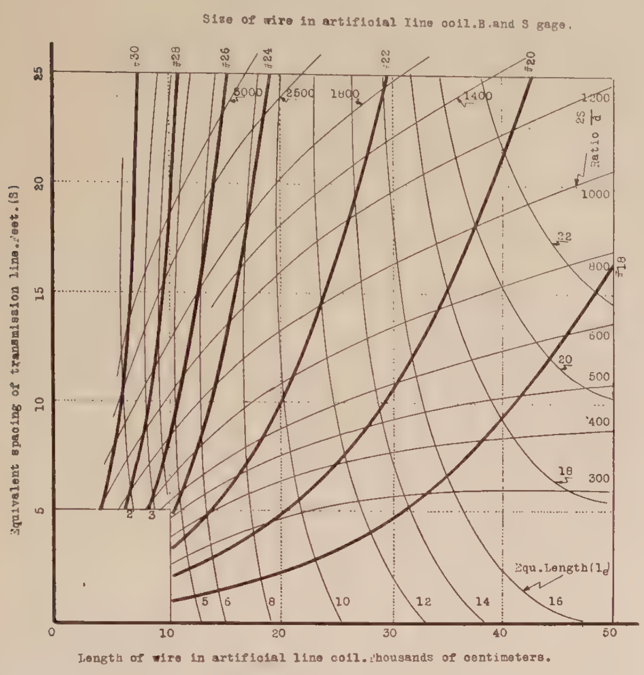

Fig. 4—Chart Showing the Relations Between the Various Dimensions and Equivalents of Round Wire Smooth Line Loop-Mile Sections

Values are calculated for a fixed value of dielectric thickness of 0.0025 in. (0.00635 cm.) Since they are all interdependent they can all be plotted to the same coordinates. For example, 20,000 cm. of No. 22 B & S wire will result in a section having an equivalent length of 10 miles with equivalent spacing of ten feet, and the ratio 2 S / d = 700, thus the equivalent conductor diameter is 0.34 in. The curves are plotted for average values of design constants and therefore give approximate results only.

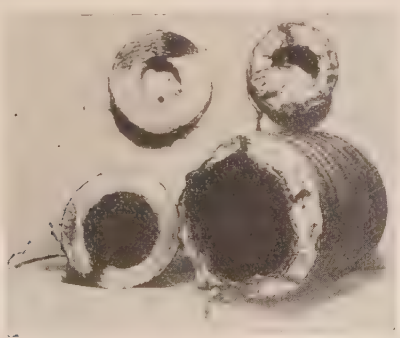

Fig. 5—Several Types of Smooth Artificial Line Coils

Upper left is lattice wound embedded in Wood's Alloy. Upper right is round wire single-phase 8 loop-mile section. Lower left is experimental three-phase coil, and lower right the final three-phase coil of 20 wire miles per section.

an oversize coil to a point where the desired ratios are obtained. The equivalent size of conductor represented by the artificial line is roughly proportional to the size of conductor actually used in winding the coil, and varies but very slightly for a small change in the number of turns. Thus unwinding the coils changes the equiva-

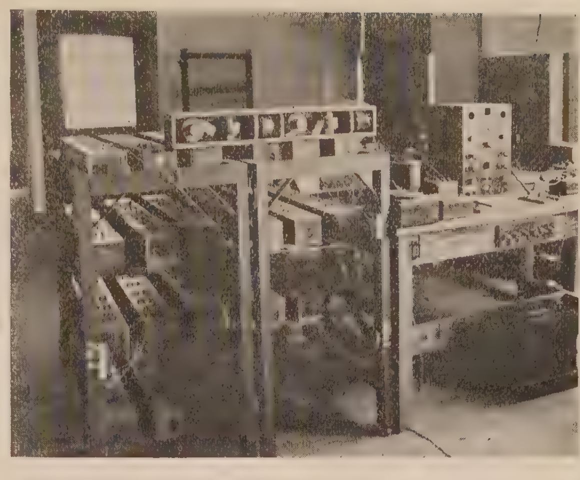

Fig. 6—The 1000 Mile Single-phase Smooth Line Assembled in Boxes. One Box is Opened to Show Arrangement of Coils

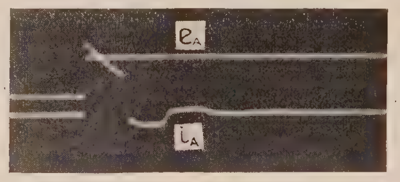

Fig. 7—The Direct-Current Transient at the Home End of 992 Miles of the Single-phase Artificial Transmission Line, the Far End Being Open

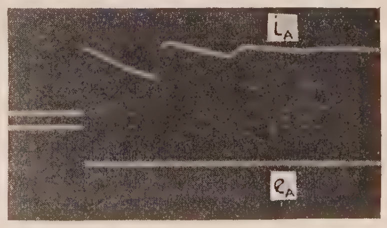

Fig. 8—The Direct-Current Transient at the Home End of 992 Miles of the Single-phase Artificial Transmission Line, the Far End Being Short-Circuited

Fig. 9—The 400-Mile Three-Phase Smooth Line, as it Stands in the Laboratory, in Use for Transient Investigations

Spacing cribs are placed between boxes to reduce mutual inductance vertically.

lent spacing rapidly, the equivalent length of line slowly, and the equivalent conductor size remains practically constant.

TABLE I

SINGLE-PHASE ROUND WIRE COILS

Loop Mile Equivalent

FINAL COIL SPECIFICATIONS

Wire size	No. 23 B&S enamel covered
Diameter of winding mandrel	1.8 inches. (4.57 cm.)
Total number of turns	792
Turns per layer	36
Number of layers	22
Thickness of dielectric, one sheet	0.002 inches. (0.0051 cm.)
Thickness of tinfoil	0.003 inches. (0.0076 cm.)
Gap in tin foil	0.25 inches. (0.6 cm.)
Tolerance	$L/C = 640 \begin{cases} +3\% \\ -5\% \end{cases}$

FINAL COIL DIMENSIONS

126 coils of this type were manufactured representing approximately 1000 miles of single-phase line. The average results are:

Weight of complete coil	1.88 pounds (0.858 kg.)
Outside diameter	3.5 inches (8.9 cm.)
Inside diameter	1.75 inches (4.45 cm.)
Winding length	$1^1/_{16}$ inches (2.7 cm.)
Coil length over insulation	1.5 inches (3.81 cm.)
Coil length over tinfoil, total	2.0 inches (5.08 cm.)
Winding depth	⅞ inches (2.22 cm.)

FINAL COIL CONSTANTS AND EQUIVALENT VALUES

	Equivalent per coil	126 coils
Resistance	7.9	996.4 ohms
Inductance	0.0326	4.112 Henries
Capacity	0.0565	7.116 Micro-farads
Leakance	0.465	58.7 Micro-mhos.
Equivalent length of line	7.87 miles (12.6 km.)	992.1 Miles (1590 km.)
Equivalent spacing	8 ft. 9 in.	8 ft. 9 in. (2.67 m.)
Equivalent conductor	No. 00 B&S	No. 00 B&S (9.2mm.)

TABLE II.

THREE-PHASE RECTANGULAR WIRE COILS

Wire Mile Equivalent

FINAL COIL SPECIFICATIONS

Wire Size, No. 28 B & S tinned bare (Rectangular)	(Width 0.104 in. (0.264 cm.) (Thickness 0.013 in. (0.033 cm.)
Inside Diameter	4.16 in. (10.6 cm.)
Outside Diameter	5.50 in. (14.0 cm.)
Total number of turns	725
Turns per layer	29
Number of layers	25
Thickness of dielectric, two sheets, each	0.003 in. (0.0076 cm.) 0.006 in. total (0.015 cm.)
Width of dielectric	5 in. (12.7 cm.)
Thickness of tinfoil	0.002 in. (0.0057 cm.)
Width of tinfoil	6 in. (15.2 cm.)
Gap in tinfoil	0.375 in. (0.95 cm.)
Length of layer	4.0 in. (10.2 cm.)
Core length	5.00 in. (12.7 cm.)
Over all length	5.5 in. (14.0 cm.)
Tolerance	$L/C = 160 \pm 10$ per cent

FINAL COIL DIMENSIONS

60 coils of this type were manufactured, representing approximately 400 miles of three-phase line. The average results are:

Weight of complete coil, approximately	7.5 pounds, (3.4 kg.)
Outside diameter	Varies from 5.5 to 5.8 in. (14 to 15 cm.)
Inside diameter	4.125 in. (10.5 cm.)
Over all length	Approximately 5.5 in. (14 cm)
Winding depth	Varies from 0.69 to 0.87 in. (1.75 to 2.2 cm.)

FINAL COIL CONSTANTS AND EQUIVALENT VALUES

	Per coil	Total average, per wire
Resistance	5.51 to 6.02 ohms	114.0 ohms
Inductance	0.041 to 0.043	0.84 henries
Capacity	0.251 to 0.312	5.25 microfarads
Equivalent length of line	19.1 miles (30.5 km.)	382.75 miles (613 km.)
Equivalent spacing	144 inches (3.56 m.)	144 inches (3.56 m.)
Equivalent conductor diameter	0.426 in. (1.08 cm.)	0.426 in. (1.08 cm.)

Both sets of lines were manufactured by the General Radio Company of Cambridge, Mass.

CONCLUSIONS

Artificial transmission lines can be successfully built with distributed constants, which will in the main duplicate the behavior of actual transmission lines, not only under steady state conditions but also under transient conditions. Certain properties of the materials used in the coils introduce effects in the artificial line which are not present in the actual line, and the change in dimensions causes some of the effects present in the actual line to be absent in the artificial line. However, as shown by the correspondence between the experimental work and the theory for relatively simple cases, the results of these divergences from exact equivalence are very small, since the discrepancies are of secondary nature, and a great deal of information can be obtained by the use of such artificial lines in studying transient and other conditions. Single-phase lines can be easily and accurately duplicated. Three-phase lines require more complexity of circuit, particularly where special configurations of line or special load conditions are to be represented, but the method of design and construction is sufficiently flexible to allow of this being accomplished. The accurate introduction of the ground plane effects and mutual inductance between wires require further analysis and study and the possibilities of duplicating networks will be developed with further experimental work. Complete transmission systems can be represented by such coils, but in order to be fully useful the effect of terminal apparatus must be introduced by artificial equivalents as well, and this is the subject of separate investigations at the present time. From the economical standpoint this type of transmission line is cheap, compact and rugged.

The Influence of Gaseous Ionization and Spark Discharge on Fibrous Insulating Materials and on Mica

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Review of the Subject.—*It has been suspected for a long time that gaseous ionization in air layers and pockets inside of composite insulation results in deterioration and shortening of the life of the insulation. Experiments described in the paper show that within a very short time fibrous insulation exposed to such ionization rapidly loses its mechanical and electrical properties. Mica is shown to be practically immune from this type of deterioration.*

The outer paper wrappers of the armature bars of high-voltage generators frequently show after operation, the presence of numerous small holes in those portions within the slot. These holes apparently do not penetrate beyond the first layer of mica. Experiments are performed indicating that these holes are due to the slow oxidation of the most vulnerable fibers in the insulation, due to the presence of ionization of the air layer between tooth and coil side. The experiments indicate methods for limiting the volume and extent of such pitting.

The influence of ionization and spark discharge on mica is studied qualitatively in some detail, and the results indicate that mica is practically immune from uniform layers of ionization in a thin air film. The most dangerous condition for mica is a spark discharge playing over its surface. Such sparks fasten on any surface flaws, leading to splintering and ultimate breakdown. The worst condition for mica is the presence of an isolated discharge point on one side in relation to a fairly wide conducting area on the other side of the insulation containing the mica. Under such circumstances mica is completely disintegrated within a short time at voltages in the neighborhood of 40 kilovolts with air gaps in the neighborhood of a 0.5 millimeter.

CONTENTS

I. The Influence of Gaseous Ionization on Fibrous Insulating Materials

THE presence of ionization, or continuous breakdown and recombination, of air in thin layers is easily observed with two pieces of plate glass, a tinfoil electrode on the lower side of one, and a water electrode on the top side of the other, as used by Dubsky[1] and others. With mica on other spacers between the plates, and voltage on the electrodes, when viewed in a dark room luminous ionization appears at a sharply marked definite value of voltage. The use of plate glass is important as otherwise the film is not of uniform thickness, and the luminous ionization occurs in patches.

This arrangement appears very suitable for studying the influence of ionization in thin films, on insulating materials. As a preliminary test a sheet of horn fiber was put between the glass plates, and an air layer introduced next the horn fiber by means of several small spacers of the same material, 0.012 in. thick. Sufficient voltage (22,000 volts) was applied to fill the air layer with bright luminosity. The bright layer was broken by dark patches where the fiber was apparently bent or kinked and so touching the lower side of the upper glass plate. One of the separators was intentionally made quite large, filling about one quarter of the entire field. Over this piece also light corona patches of low intensity and small area were seen, showing imperfect contact with the glass, notwithstanding the considerable weight of the latter with its water electrode. After six hours' operation the appearance of the discharge had changed considerably, streaks of increased brightness and a number of points of high intensity appearing. The run was continued for a week with voltage on for nine hours a day. On removing the sample it was found that the gum or varnish of the original surface was soft and sticky, and had drawn up into a series of humps or drops, leaving intervening areas exposed and with a dry appearance. Under the microscope the tops of the varnish drops appear slightly pitted, and after further prolongation of the test, small white crystals appear, suggesting some process of disintegration or chemical change. After the first day of voltage application the sample if removed, emits an acrid smell suggesting a mixture of ozone and some other product of chemical action—the odor is still present after standing in the open for ten hours. After a week's run under voltage, the original light brown shade of the sample is noticeably darker.

In order to study the matter further a large apparatus was prepared consisting of a sheet of untreated cardboard 0.042 in. thick into which six (6) windows each 2 in. square were cut. These windows were closed on one side by samples of (1) oiled horn fiber (0.012 in.), (2) japanned press board (0.0095 in.), (3) shellaced express paper (0.007 in.), (4) yellow varnished cambric (0.010 in.), (5) black varnished cambric (0.0136 in.), (6) varnished express paper (0.0045 in.). The varying thicknesses were brought to the same value by paper fillers back of the several samples. The assembled samples and cardboard were then laid, windows up, on a piece of ¼-in. plate glass, and a second piece of ½-in. plate glass laid over the upper face of the cardboard. A brass plate beneath and a water electrode on the upper plate completed the set up. A run of 50 hours, starting with bright corona in the six win-

1. Trans. A. I. E. E., XXXVIII, 1919, p. 537.

dows, produced changes in the appearances of all the surfaces, either in the form of white patches, or a blurring of the original glossy finish. At the end of the run an effort was made to compare the insulation resistance of fresh samples with those that had been exposed to corona. A Weston high-sensitivity galvanometer (1.5×10^{-10} ampere = 1 mm. of scale) and 20 volts d-c. were used, the testing electrodes being provided with the usual guard rings. The electrodes were of tin foil, carefully smoothed, backed with blotting paper, and a 10-lb. weight on top. Owing to the small size of the samples, and to the difficulty of obtaining uniform electrode contacts, no accurate determinations of resistance were possible. However, observations repeated many times and with careful effort to eliminate the influence of variations in the contact conditions, showed beyond question, that the insulation resistances of the exposed samples were definitely lower than the values for fresh samples. The average ratios of final to initial resistances were:

Black varnished cambric........0.6
Varnished express paper.........0 to 0.03
Yellow varnished cambric.......0.2
Japanned press board...........0.25

It appears that owing to the variations in the surface contacts of electrodes, insulation resistance cannot be used as a certain indication of the deterioration caused by corona. For the same reason it would appear that all electrical tests, on small samples, or single layers, are open to question in the matter of accuracy. The results, though roughly qualitative only, are quite definite and indicate that even with brief applications, fibrous insulation suffers deterioration in the presence of gaseous ionization.

It appeared desirable also to study the influence of ionization on the mechanical structures of the various samples. The endurance tests were, therefore, extended with this aim in view. The various types of insulation referred to, with two samples of clear white mica added, were subjected continuously for a long time to the corona or ionization in an adjacent air layer. Except for occasional brief interruptions, the test was run for fifteen hours out of each day for eight months. At the end of that time all of the fibrous materials were in bad condition. The thinner papers were perforated with numerous small holes, the polish of calendered materials, such as fullerboard, had disappeared, and all of the fibrous materials including the treated cloth, had completely lost their tensile and tearing strength, being brittle and crumbly, and in some cases darker in color. Several of the samples had the dark and dry appearance which results from prolonged high temperature. During the tests, however, there was no apparent elevation of temperature above that of the atmosphere, the whole set up remaining cool. It is known from other tests that the losses in the air films are not great, and would, therefore, not raise the temperature appreciably. The changes in the materials, therefore, are apparently due to chemical processes attendant upon the active ionization of the air. The samples of mica had on them a few cloudy patches. These were apparently oxides of the adjacent materials, as they could be readily wiped off. The mica itself was apparently unaffected, remaining clear and with bright surfaces.

Some attempt was made to determine the most active chemical agent arising in the process of ionization in air. A polished brass plate separated from a sheet of glass by an air layer and with voltage terminals above and below, the whole open to the surrounding air, takes on first a black appearance and finally near the edges or regions of high electric intensity, deposits of green and white appear. The test was varied by overlapping in echelon form a number of thin sheets of brass, thus providing air layers of different thickness. In this case the black oxide is deposited in decreasing thickness inward from the edges of the sheets, *i. e.*, over the surfaces of the successive steps, and apparently with great uniformity, as regular interference color films are seen, the lines of the various colors showing clearly the distribution of the electric intensity.

If the air space in which the ionization occurs is shut off from the surrounding air a quite different result is observed. A window 3 in. by 8 in. was cut in a piece of thin sheet bakelite which was then sealed with wax between a polished brass plate and a piece of plate glass; a water electrode was mounted on the top side of the glass. Voltage causing copious ionization in the air space was applied between the brass plate and water electrode. After a day a very thin layer of black oxide, scarcely dimming the brass surface, had formed, but thereafter there was no further deposit, although the test was extended over many days. Moreover the luminous corona had changed in appearance. Instead of the uniform glow pertaining to the first stages of ionization in thin films, on close observation it was seen that the whole field was filled with points or sparks of breakdown; not fixed but in a state of violent disturbance or motion, as though under mutual repulsion.

It is suggested from the foregoing, that active oxygen or ozone is the first and most copious product of the ionization of air. That in regions of very high intensity nitric oxides may also be formed. That in closed air layers the amount of oxygen so liberated is limited and a state of equilibrium is reached in which the residual gas is in a state of continuous ionization and recombination. The amount of ozone and nitric oxides which may exist in equilibrium with air under electric discharge varies with the temperature. According to Almand (Electrochemistry) practically no nitric oxides are present at temperature under 1000 deg. cent., while ozone in amounts up to 10 per cent may occur at ordinary temperatures. It appears certain, therefore, that the principal agent in the destruction of insulation by contact with ionized gas is oxygen or ozone, in a nascent or highly active state.

A further interesting feature of this ozone is that it, or its gaseous products, are absorbed by fibrous insulations, and these latter will give them off for some time. A piece of treated cloth was exposed for a day to active ionization with several portions of it screened. On removing and laying the cloth on a piece of polished brass the latter became blackened with oxide under the portion which had been exposed, but remained clear and polished under the portions which had been screened. These after-effects of ionization and absorbed gases could be traced over several days.

The relative resisting powers of different materials to the products of gaseous ionization is a question of great importance. Although the foregoing tests are qualitative rather than quantitative in character, they do show that a rather wide variety of standard fibrous insulation is subject to a rapid deterioration, while mica has a resisting power immeasurably greater. Moreover, it appears fair to conclude that the vulnerability of different materials follows approximately the degree of susceptibility to oxidation.

II. The Influence of Gaseous Ionization and Spark Discharge on Mica

The following experiments were undertaken with the aim to determine the conditions surrounding the failure of mica as it occurs in built-up insulation. It is known that such insulation often contains layers of entrapped air in which gaseous ionization is present. The influence of this ionization on the structure of mica, however, has apparently not been studied. Further, it has frequently been noticed that the outer paper cells of the armature conductors of high-voltage alternating generators are perforated after prolonged operation with numerous small holes, apparently originating at the points of contact between the armature coil and the iron laminations at the side of the slot. These perforations are apparently stopped by the underlying mica. However, the limits of this apparent resistance to small spark discharges are also unknown.

The influence of gaseous ionization in air in thin layers adjacent to clear white mica was studied by placing two samples back of two windows cut in a sheet of japanned press board 0.0096 inches thick, the combination being placed between two sheets of plate glass laid flat on a lower brass electrode. A water electrode was formed on the upper glass plate permitting visual observation of conditions in the air layer and on the surface of the mica. With this arrangement the mica was subjected to a bright luminous layer of ionization for fifteen hours out of each day over a period of eight months with occasional interruptions for inspection. At the end of that time the samples of mica had on them a few cloudy patches. These presumably were oxides of the adjacent materials as they could be readily wiped off. The mica was apparently unaffected, remaining clear and with bright surfaces, and showing under the microscope no differences from fresh samples of mica. Samples of other fibrous insulation, in adjacent cells, were badly perforated and had lost their tensile strength, elasticity and other mechanical properties. Mica, therefore, is highly resistant to the action of gaseous ionization and is probably not injured by such ionization as occurs in standard insulation.

Turning to the study of the influence of spark discharge, a large number of observations were made with various types of point, and other forms of discharge electrode. In all of these tests conclusions are based on the study of the mica structure as shown under a high-power microscope. Since even the most perfect pieces of mica rarely offer areas of more than 1 or 2 sq. cm. which are free from flaws or irregularities, it is difficult to find two samples approximately alike, and electrical tests of the state of the mica after exposure are impossible. Moreover, quantitative results as regards the relation between applied voltage and the resulting state of the mica, are also very difficult for the same reason. It is, therefore, possible to draw only very general conclusions from these tests.

The principal spark gap consisted of from one to four steel or brass rods, 0.125 in. diameter each, 2 in. long, and tapered to a fine point at one end. These were mounted by screw threads in a brass plate 3 in. by 4 in., supported on hard rubber pillars at the corners. This was placed on a glass plate 1 mm. thick, which rested on a grounded brass electrode below. The 0.001 in. mica was placed between the point and the upper surface of the glass, and voltage applied between the upper and lower brass electrodes. The glass is necessary to prevent direct puncture or flash around the edges of the mica. With gaps 0.5 mm. long, and 10,000 volts, effective, brilliant discharges play over the surface of the mica. Neglecting the voltage over the spark itself, this corresponds to a gradient of about 140 kv. per cm. in glass and mica. This discharge was continued on a sample of 0.001 in. clear white mica for 15 hours a day for eight days. At the end of that period the mica was found to be unaffected save for a surface deposit, apparently of oxides of the material of the points, since it could be readily wiped off. The steel points are better than brass as giving less deposit and better retaining their points.

Using this arrangement the voltage was then progressively raised and maintained for brief periods at each value, with microscopic examination of the surface of the mica at each step. As the surface sparking from the central point becomes very copious and bright, and as these streaming sparks have an effect of their own, the use of a single point permits more definite conclusions as to the action over different portions of the surface.

After a run of 10 kv. the surface was found to have a thin white deposit, which under the microscope appears to consist of small white transparent crystals. The deposit is usually not immediately under the point but begins a few millimeters away, spreading radially

outward for a few millimeters. The deposit can be rubbed off, though with some difficulty. The small particles look like chips of mica, but there is no evidence that the surface is broken.

With a fresh sample of mica, at 15 kv. long thin radial surface sparks set in. The surface deposit occurs as above, and may be wiped off.

At 20 kv. the long radial sparks are frequently fat and white. After 1¾ hours, there is a brown and white deposit around the point, the former apparently being the oxide from the point. The deposit was rubbed off, and under the microscope there was some evidence of surface destruction in the form of small splintered spots. In view of the subsequent observations it is not certain that these spots were not fragments on top of the surface, rather than breaks.

With a fresh sample, at 25 kv. for one hour, the white deposit is now entirely absent, and there is a wide space all around the point clear and apparently unaffected. On the outer edges of the mica white patches appear, which under the microscope are seen to be the result of the cracking and splintering of the surface. After one hour further at 25 kv., on the same sample, the central clear area is reduced in size but is still clear. and unaffected. The outer patches are greatly increased in number and extend over the outer area in small groups, each of which is seen to have as a focus a small puncture through the mica sheet. This focus is always nearest the central discharge point, the white patches radiating out from it. Raising the voltage to 30 kv. on the same sample, after two hours it appears that the white patches seem to mark the points where the charging current to the electrode below passes over the surface as sparks, into the spaces between the layers of mica, or through a puncture or a flaw to the glass below. The whole area beyond the puncture which forms the focus of the patch, is badly splintered up in the planes of the layers, resulting in interference color films, wide air spaces, etc. After this run, the white patches are drawn in, holes and perforations with burned edges form in the outer regions, but there is no clear evidence that the area under the point has suffered disintegration. There is some slight surface deposit and some suggestion of color films, but the surface itself is apparently still intact.

Using a fresh sample, at 33 kv. the outer area around the discharge point shows the characteristic chipping of the surface after 1-2 hours, at which time the mica and 3/32 in. glass beneath it both punctured. It appears that the disintegration starts where the surface spark passes to a local imperfection, there working through to the glass below, or into air spaces between layers of mica. The suggestion, therefore, is that the mica breaks down under the effects of surface leakage, rather than under direct puncture.

With a further fresh sample of mica, presenting about 5 sq. cm. apparently entirely free from flaws, backed up by two pieces of ⅛-in. plate glass, 18 in. square, 33 kv. was applied over the same steel point and gap. After one hour with copious surface sparking the usual thin white deposit was seen around the point. On removing it by rubbing with chamois skin, the surface was found to be apparently unaffected. Continuing the run at 40 kv. for another hour, the mica presented the same appearance around the center but there were many pronounced white areas at a distance from the point. Under the microscope these were seen as before, to be of stream shape away from the spark point, to start from a hole or flaw, and to be due to the splintering of the surface of the mica. This splintering was now found to be on the lower side of the mica next to the glass. It is thus caused by spark over the top surface of the mica, through the holes, and beyond this between mica layers and between mica and glass. Continuing this run for a further five hours, the white deposit around the central point was rubbed off with some difficulty, and was found to consist of the chipping of a stray splinter of mica adhering to the surface near the point. In this run this splinter, noticed under the microscope before starting, was thought to be a surface flaw, and it was placed immediately below the point to see if it would cause failure. The spark, however, only chipped the edges, causing the deposit. On rubbing, the latter, together with the original splinter, disappeared, and the surface was found to be unaffected. The voltage was now raised to 42.5 kv. and after 2½ hours the whole mica sheet of area about 10 sq. in. was completely disintegrated. There remained only a few splintered and whitened chips. Similar chips of mica were found around the outer edges of the glass plate well beyond the sparking area. This destruction of mica is apparently a continuation of the splintering process originating in the passage of sparks through small flaws and imperfections. It was found, for example, that although whitened and splintered, there remained, immediately under the point, a small area which gave evidence that the surface was still intact.

From these experiments, therefore, it is suggested that in the presence of spark discharge, the region around the point becomes ionized and conducting, thus in effect increasing the area of application of the voltage. This extension may pick up a local imperfection, but always leads to copious sparking over the surface, and results in splintering and ultimate failure. Mica thus has a much higher resistance to direct puncture than it has to the influence of sparks passing over its surface. It is known that the surface leakage resistance of mica is not high, consequently, if the mica is backed up by a wide area of dielectric, the point discharge on its surface must have a tendency to deliver charging current over the surface, to the dielectric below. These charging sparks naturally fasten on any local imperfections in their path, and then either by temperature or other action, lead to progressive destruction of the mica. It appears, therefore, of great importance in built-up insulation, to prevent this side

flashing or surface sparking whenever mica is used. This can best be done by the elimination of voids or air spaces next to the mica, that is by intimate contact between the mica and adjacent insulating material.

Breakdown Voltage on Thin Sheets of Mica under Spark Discharge

The following experiments were conducted with the aim to eliminate the surface sparks referred to above, to concentrate as much of the spark as possible on a perfect area of mica surface directly under the discharge point, and to develop a method by which the behavior of different materials under spark discharge might be studied. In the foregoing experiments there was much brush discharge and ionization from various parts of the gap structure which probably increased the surface leakage. Therefore, the point was made sharper, and fused through the closed end of a glass tube exposing only one or two millimeters of length. Also a second similar point was placed on the underside of the mica, removing the glass plate about one inch below; in this way the surface sparks are greatly reduced. The arrangement was as shown in Fig. 1. The points were of platinum tapered down from No. 20 B & S wire, and

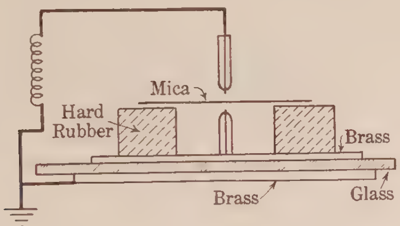

Fig. 1

were 0.8 mm. apart. The mica was supported midway between the points, not touching either. The lower point was mounted on a brass plate, and then below, a sheet of glass and the lower grounded electrode. In this way the spark carried practically the entire charging current of the condenser formed by the glass and two brass plates. Since the resistance of the spark in this arrangement is probably quite low it may be assumed that practically the entire voltage is concentrated on the mica. The tests, therefore, give approximately the electric or puncture strength of mica of the particular thickness studied, in the presence of spark discharge. The method, therefore, does not test the mica under the conditions under which it is used in practise, but provides means for introducing the time element into the failure of mica under the action of the spark. A piece of clear white mica 0.001 in. thick will apparently stand up indefinitely in this gap under the bright crackling discharge at 5000 volts, 60 cycles. Puncture occurs between 6000 and 7000 volts, after intervals of several minutes. Somewhat more uniform conditions obtain in a sphere gap, and for most of these experiments 0.5 cm. diameter spheres, 0.13 cm. apart, were substituted for the points. A large number of observations were made with this gap of the time during which various samples of mica would stand up under sparks at different values of voltage. Following is a typical set of observations on best selected white mica, rated at 0.001 in. thickness. In all cases the sample was chosen so that a clear area free from flaws was placed in the gap. It was rarely possible to find such areas larger than 4 sq. cm. Table I shows the time of application of successively increasing values of voltage up to the instant of puncture;

TABLE I

Volts	No. 1	No. 2	No. 3	No. 4
thickness	0.0007 in.	0.0006 in.	0.0006 in.	0.00065 in.
6250	1 min.	1 min.	1 min.	1 min.
7500	1 min.	1 min.	1 min.	1 min.
8750	40 sec.*	50 sec.*	1 min.	1 min.
9375			?	15 sec. †
10000			2 sec.*	

*Breakdown under spheres
†Breakdown at imperfections at distances from spheres

It will be noted that in several of the above cases the first breakdown occurred at an imperfection at a distance from the center line of the gap. This type of rupture was quite common, and if the spark was allowed to continue, playing over the surface and through the distant puncture, the mica soon broke down on the center line. Several specimens were removed before the puncture had passed from the outlying defect to the center line of the gap. In these the surface, when examined under the microscope, was found to be blistered, or splintered and blackened. Thin white mica has the same properties as the thicker grade, but amber mica will not stand up at all under the action of the sparks. Using amber mica in the above gap, 3750 volts was the lowest value at which the air in the gap would break down, and puncture of the amber mica follows simultaneously.

Table II gives a summary of further tests of the influence of the spark between spheres. In these the length of the spark gap was varied, the mica being

TABLE II

Spark Voltages to Puncture Mica between 0.5 cm. Spheres

	Clear Mica				
Thickness...	0.001—0.0012 cm.			0.002—0.0026 cm.	
Gap. cm.....	1.25	0.25	0.37	0.125	0.25
kv.	8	7	9.5	9	11
	6	7	9.5	10	12
	8	11	10	11	10
	10	8.5	12	12	11
	8	11	13	11	9
	9	9.5	9.5	13	10
	7	8.5	9.5		10
	9	7	9.5		10.5
	7	7	9.5		10
	7	8	9.5		11.5
	9	9	9.5		9
			9.5		9
			9.5		11.5
					11
Av. kv.	8	8.8	10	11	10.4

placed midway between the spheres. The voltage was raised by steps of 500 volts of 1 minute duration each. The readings give the values at which failure occurred after less than one minute of application.

Owing to the uncertainty as to the drop of voltage in the body of the spark, approximate conclusions only, may be drawn from these tests. If the voltage drop in the spark is negligible, the breakdown voltages with the short gaps indicate a dielectric strength about the same as that of mica of the same thickness placed directly between spheres, and, therefore, that the spark does not lower the breakdown voltage appreciably. However, the results for longer gaps, give, on the same assumption, higher values than normal for dielectric strength. Hence we have the conclusion that there is some voltage drop in the sparks, and that these do not lower the breakdown voltage appreciably, certainly not by more than the voltage drop in the spark.

Influence of Discharges from Iron Laminations

In order to study the influence of a large number of small point discharges such as occur between the iron laminations and the surface of an armature coil, an electrode was constructed consisting of a number of iron laminations placed side by side. In this way an elec-

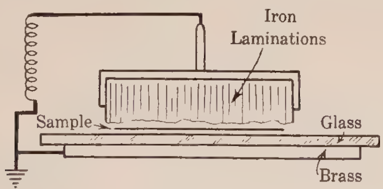

Fig. 2

trode 5 cm. square was made, the flat surface of which consisted of the edges of the laminations. In order to accentuate the sparking effect of laminations, before assembling all were given a number of small tooth indentations. The general arrangement is shown in Fig. 2.

The above electrode was placed 0.5 mm. above a piece of clear mica about 4 by 4 cm. which was thus completely covered. In this arrangement the mica is entirely free from the surface discharge from the edges of the electrode, but is exposed to the discharges from the points of the laminations, and also to the gaseous ionization within the gap. At 40 kv. there was a copious surface discharge from the edges of the electrode and over the glass. The region under the electrode appeared to be free from localized sparks but was filled with a violet glow. The run was continued for twelve hours a day over a period of nine days. Although before the test the mica was not entirely free from surface scratches, at the end of the run there was no evidence of deterioration of the mica. At the end of this run the electrode was allowed to rest on the surface of the mica. After twelve hours a slight deposit or iron oxide was found on the surface of the mica. This, however, was easily rubbed off and there was no evidence of deterioration of the surface.

Gray fullerboard was next tested under the laminated electrode with the electrode flat on the fullerboard and about two pounds weight to hold it in position. After eight hours at 37 kv. the projecting edges of the fullerboard were plentifully punctured by the sparks discharged from the edges of the electrode. The surface of the fullerboard under the electrode was slightly marked by the teeth of the laminations and possibly with the oxide, but there was no other evidence of structural deterioration. This run was continued for four days longer, after which time it was found that while in appearance the fullerboard was little changed, it had lost the greater part of its elastic flexibility. On bending it cracked much more readily than a fresh sample.

A second sample of fullerboard was next tested with a 0.5-mm. air gap between the fullerboard and electrode. The aim was to provide a more copious layer of ionization. After five days at 37 kilovolts it was found that the fullerboard was perforated where its edges projected beyond the electrode, these perforations being due to the sparks leaving the outer edges of the electrode. Under the electrode the polish of the surface was gone and there were a number of spots of brown oxide and there were several clearly marked perforations. There was no evidence of burning, that is, there was no blackening, but the perforations appeared as though they had eaten their way through slowly. They are thus similar to the holes which have been noticed in the outer paper cells of armature coils.

From the foregoing it appears that an air gap between the iron laminations and the coil is more dangerous to fibrous insulation than when there is a close fit between slot and coil. This bears out the conclusion from the tests on mica, indicating that it is the volume of the spark that is especially dangerous. When there is an air gap between slot side and coil and a prominent point on the laminations, the point discharges to a relatively wide area on the coil give a fat spark and surface discharge. When there is no gap or a very narrow one, neighboring points come into play thus reducing the volume of discharge per point. The action due to these small sparks is slow. They may after a long time eat through fibrous material but are usually stopped by mica. If, however, there is an air layer between paper and mica the spark is likely to increase in volume, giving a surface discharge over the mica to which the latter may yield in time.

Further Tests with Surface Sparks

In order to study the influence of sparks passing over the surface of mica, the apparatus shown in Fig. 3 was constructed. Sparks passed between the smooth rounded edges of the electrodes A and C cover the surface of the mica placed between them. The distance between A and C was 2 cm. At 35 kv. there was a band

of snappy sparks across the full 5 cm. width of A and C. After some time the sparks concentrated on one on the lower edge of A which fused slightly, depositing a film of brown oxides very hard to rub off. After about 8 hours run at 35 kv. there was no certain evidence that the surface was affected. Rounding and polishing the edges of A and C, another run was started at 40 kilovolts, and after some time the bulk of the sparks appeared to concentrate in one region, but now this region is apparently determined by the mica and not by the electrode. The brown deposit was absent. Continuing this run for eight hours a day for six days, the spark concentrates in one general region, though playing over some slight width of surface. Failure first starts in the form of a slight blister appearing near one electrode. There is a gradual growth or extension of this blister and then a definite concentration of the spark in a short length reaching towards the other electrode. On examination of the mica it was found that under the line of this spark there was a sharp cleavage of the mica. This cut, or straight crack, extends further with the further application of voltage, and finally its edges crack and blister. Under the microscope the crack is seen to work back towards the

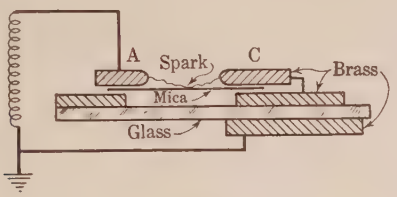

Fig. 3

electrodes and to a point where the sparks join the mica surface over the electrode. The most serious deterioration, however, sets in at a greater distance from the electrode. With further time this sharp crack develops small spark holes with burnt edges at irregular intervals. The spark now passing though these holes and over the lower surface of the mica as well as the upper surface. After a run of forty hours at 40 kv., the surface spark in this test begins to split the mica. After sixty hours, the mica is splintered and punctured in a number of places.

Conclusions

1. Fibrous insulating materials rapidly lose their electrical and mechanical properties in the presence of internal ionization of adjoining air layers. They become brittle, lose their tensile and tearing strength and their smooth calendered surfaces rapidly disappear.

2. From studies of ionization in thin films next to metal surfaces, it appears probable that the active agent affecting insulation is oxygen, or ozone in a nascent or highly active state. In regions of very high electric intensity, resulting in bright sparks, nitric oxides may also be formed. In the closed air layers within insulation the amount of oxygen or ozone liberated is limited, and a state of equilibrium is reached in which the residual gas is in a state of continuous ionization and re-combination. It is certain, however, that few, if any, nitric oxides are present and that the principal agent in the destruction of insulation by contact with ionized gas is ozone, which may be present in amounts up to 10 per cent at ordinary temperatures.

3. The small perforations in the layers of fibrous insulating materials, frequently noticed in the outer surface of armature insulations next to the iron laminations, are due to the slow oxidation of the more vulnerable fibers, due to gaseous ionization or low-intensity spark discharge. The phenomenon has been observed in the case of single sheets of insulating material exposed to ionization of an adjacent air film. The action is quite slow even in the presence of copious ionization, if no point discharges are present. The penetration of these holes is usually stopped by mica.

4. While no direct experiments on the dielectric puncture strength of mica have been attempted, the results of tests between points and small spheres are in conformity with the observations of Rayner which are the basis of the figures given in the Standardization Rules, A. I. E. E.

5. Copious gaseous ionization in thin air layers between the smooth surface of mica and glass has no effect on the mica, after a practically continuous run of ten hours out of every twenty-four, over a period of eight months.

6. Under spark discharge from a sharp point through a gap of 1 to 2 millimeters to the surface of mica, the mica begins to splinter and crack at from 35 to 40 kilovolts. This failure, however, does not take place in the region under or immediately around the metal point but at distances of ½ to 2 centimeters away from the point. Discharge from several metal points in parallel and close to each other leave mica immediately under the points unaffected, but splintering and failure take place at from 35 to 40 kv., in regions at some distance from the points.

7. Mica placed close to an electrode made up of iron laminations laid side by side and subjected to voltage, is not affected, after prolonged runs, in the region under the electrode. This immunity holds whether the electrode is separated from the surface of the mica by a layer of air ½ mm. thick, or whether the electrode and mica are in contact with each other. Under the same conditions of voltage and spacing gray fullerboard loses its elastic flexibility and its polished surface, if an air layer is present, although to a lesser extent when the electrode and insulation are in contact.

8. Mica soon begins to splinter and split under the action of a bright spark discharge playing between electrodes over the surface of the mica.

9. The general conclusions are that mica is most vulnerable to sparks playing over its surface. The discharge from neighboring metallic points ionizes the air in the immediate neighborhood of the points,

rendering the air to some extent conducting. From this conducting region the charging current to the adjacent capacity of the solid insulation takes the form of sparks playing over the surface of the mica. These sparks attack local imperfections in the mica leading to progressive splintering which gradually works radially inward toward the central point. Below 30 kv. these phenomena take place very slowly; at voltages between 35 and 40 kv. splintering and progressive failure set in after a few hours.

An air gap between the electrode, consisting of iron laminations, and the insulation of a coil is more dangerous to the solid insulation than when there is a close fit between slot and coil. It is the volume of a discharge spark that is dangerous. When there is an air gap and prominent points on the laminations, discharges from any metallic point through the gap to a relatively wide area on the coil produce a fat spark, whereas with a very thin air gap adjacent metal points come into play, thereby reducing the volume of discharge per point.

10. The small perforations frequently found in the outer fibrous layers of mica folium armature insulation, next to the iron laminations, are due to slow oxidation by ozone which is produced by the ionization or spark discharge. Mica stops this penetration owing to the low intensity of the ionization, to the close proximity of adjacent perforations, and to the absence of surface discharge over the mica. Danger to the mica would arise from a high point on the laminations, in conjunction with a separation of the outer fibrous paper layers from the surface of the underlying mica.

Bibliography

Rayner. *Journal Institution of Electrical Engineers*, No. 49, 1912, p. 3.

Curtis. Bureau of Standards, *Scientific Paper*, No. 234.

Fleming and Johnson, *Electrical Review* (London), Vol. 71, 1912, pp. 444, 514.

Wiggins, F. *Electrical Review*, 71, 1912, p. 564.

Weeks, J. R. Dielectric Constant of Mica, *Physical Review*, 1922, Vol. 19, p. 272.

Properties and Uses of Mica, *Journal Institution of Electrical Engineers*, 1922, Vol. 60, p. 339.

Flight, W. S. Effect of Heat, *Journal Institution of Electrical Engineers*, 1922, Vol. 60, p. 218.

Poole, H. H. The Electrical Conductivity of some Dielectrics, *Phil. Mag.*, 1921, Vol. 42, p. 488.

Silsbee and Homan. *Journal of the Washington Academy of Sciences*, Vol. 9, May 4, 1919, p. 252.

The U. S. S. *Colorado* the latest dreadnaught of the U. S. Navy which is now having her fire control apparatus installed at the Brooklyn Navy Yard, was removed to Pier 86 next to the *Leviathan* for visitation by the Marine Congress representatives and the general public for two days. Hundreds of prominent marine engineers who visited the *Colorado* were shown the marine features of the Westinghouse electric drive. About 15,000 people in addition were escorted around the upper decks.

STATE RESPONSIBILITY FOR SUPERPOWER*

That water powers are a natural resource, and that whenever owned or controlled by public agencies that ownership and control should be permanently retained, is a fundamental principle of the Federal policy. There appears no good reason why it should not be equally a principle of State policy to the full extent that the States have ownership or control, either concurrently with or independently of the Federal Government. The principle that values inherent in a public resource developed and used in the performance of an essential public service, by an agency created by law for that purpose, shall not be capitalized in excess of amounts actually expended in acquisition, is also a fundamental feature of the Federal policy, applicable in all cases where power sites are licensed under the Federal law. This principle applies not only to the site itself, but to all structures and equipment, erected or used on the site or in connection therewith. Whether our water powers have great value or not, the public fear that their values will be capitalized at the expense of the rate payer is groundless as far as sites under Federal ownership or control are concerned, and these sites involve 85 per cent of the total water powers of the United States. This provision of the Federal law is not hindering in any degree the financing and construction of water powers under Federal control, and a similar provision would not hinder the development of the remaining 15 per cent subject to exclusive State control.

State and National Cooperation

Since water powers will form an essential part of any comprehensive superpower system, the controversies concerning them require early solution in order that the way be cleared for carrying out the general program. This program will be much wider than the territory or the authority of any individual State. State interests must nevertheless be harmonized in a policy and program which will be to the common interests of them all. This will require cooperative action and reasonable uniformity of legislation. There must be no State barriers against the interchange of energy, and no type of development that cannot become an integral operating part of the combined system. Legislation which interferes with the program should be repealed or modified; necessary affirmative legislation should be had; public officials of both State and Nation should lend the program their support; and, finally, the industry itself should harmonize its own conflicting interests. It should no longer be permissible for any utility to draw plans for future extension except in such manner that interconnections may be readily effected whenever its territory merges with the territory of any other utility.

*From the third annual report of the Federal Power Commission.

Oscillographic Study of the Current and Voltage in a Permeameter Circuit.

BY W. B. KOUWENHOVEN and T. L. BERRY, JR.

Member, A. I. E. E.

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Review of the Subject.—*The purpose of the investigation was to study the form of the voltage-time and current-time curves, existing in a permeameter circuit, and to reduce the time required for the reversal of the magnetizing current. The permeameters used in the investigation were of the U-shaped yoke type. Oscillograms were taken of the current and of the induced voltage during the opening and also during the reversal of the magnetizing current.*

The permeameter, with which the investigation was started, was fitted with brass end pieces to support the magnetizing coil. The oscillograms showed that the flux change lagged behind the magnetizing current. In fact, the secondary e. m. f. continued for about one second after the current change was completed. The cause of this lag was found to be due to eddy currents set up in the short-circuited paths provided by the brass end pieces. After these were removed oscillograms showed that the lag in flux behind the magnetizing current was negligible. This brought out clearly the fact that short-circuited paths in which eddy currents may be induced should be avoided in permeameter construction.

Two new permeameters were then constructed of the same type; one of these was made with a solid core of silicon steel and the other with a laminated core of the same material. Tests of these showed that use of the laminated core materially reduced the time required for the reversal of the current.

Several different types of switches were used for opening and reversing the magnetizing current. The oscillograms showed clearly that a quick-break snap switch operating under oil is superior to other types of switches.

* * * * *

THE purpose of the investigation was to study the form of the voltage-time and current-time curves in a permeameter, and to reduce the time occupied by the current reversal to a minimum.

One of the reasons for undertaking the investigation was the fact that a permeameter of the U-shaped yoke type, that had been constructed at the Johns Hopkins University, had never given satisfactory results. This instrument read too low in flux density, B, for a given magnetizing force, H. Another reason was that a search through the literature disclosed no publications showing the form of the secondary e. m. f. curve in a permeameter.

Permeameters

The permeameter, mentioned above, was of the U-shape type. The magnetizing coil consisted of 1935 turns of No. 16 B and S wire wound on a cast-iron core 5.08 cm. square. The ends of the spool supporting the coil were of ⅛ in. (about 0.3 cm.) sheet brass. The total length of the magnetic circuit including the specimen was approximately 65 cm.

During the investigation two other permeameters were constructed. The cores of these were of high-grade silicon tranformer steel. One was fitted with a solid core of silicon steel 6 cm. by 6 cm. square and the other with a core of 0.012 (0.0305 cm.) thick laminated silicon steel of the same dimensions. The cross-sectional area of the solid core was 36 cm. square and that of laminated core, allowing the customary 10 per cent stacking factor, was 32.4 cm. square. The ends of the spools supporting the windings in these two permeameters were of bakelite. These two permeameters were wound with the same number of turns, and were also of the yoke type.

To be presented at the Midwinter Convention of the A. I. E. E., Philadelphia, Pa., February 4-8, 1924.

Circuit

The diagram of the connections used in the test are shown in Fig. 1. The current supply was taken from a storage battery, and the value of the magnetizing current measured by the ammeter A. A number of different types of switches were used for reversing the current and opening the circuit. In some cases automatic control was used for operating the switch and the oscillograph shutter simultaneously. In some of the tests condensers were placed in parallel with the primary

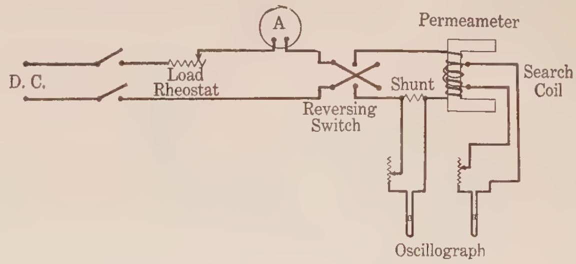

Fig. 1—Diagram of Connections

winding of the permeameter, and in others, extra inductance was placed in the circuit. These conditions are described below.

The shunt used in the magnetizing current circuit was non-inductive. The search coil consisted of 28 turns of No. 18 wire wound over the magnetizing coil of the permeameter. The e. m. f. induced in this search coil was measured by the oscillograph and the shape of this voltage curve shows the form of the e. m. f. that is induced in the secondary circuit of the permeameter.

Tests

Tests were made both of the opening and of the reversal of the magnetizing current.

Opening the Current

Two oscillograms were taken using a carbon break magnetic blow-out circuit breaker to open the magnetizing current of the permeameter with the cast-iron core. The circuit breaker was automatically tripped in this test. The results are shown in oscillograms 1 and 2, which are reproduced in Fig. 2. The magnetizing current was 7.5 amperes in both cases and in oscillogram 1 the magnetic circuit was open, while in 2 it was closed with a soft iron specimen. As would be expected the time necessary to interrupt the current was greater in 2 than in 1. Oscillogram 1 shows that it required 1.25 seconds to reduce the current to zero and in 2 it took 1.68 seconds to accomplish the same thing. A study of the oscillograms show that the secondary e. m. f. has two pronounced peaks; one when the current starts to fall, and the other when it dies to zero; also that the e. m. f. in the secondary continues for some time after the magnetizing current has been reduced to zero. The explanation of this is given below.

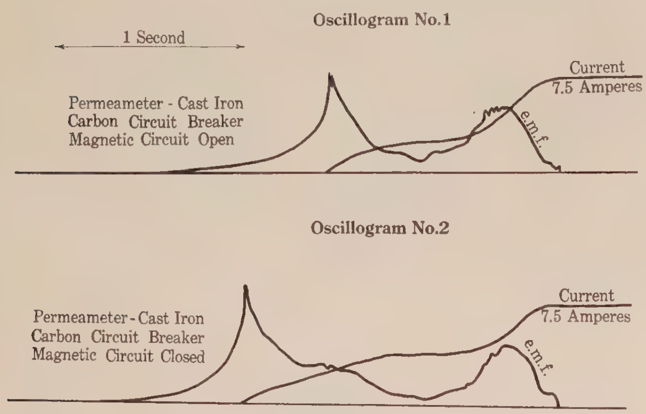

Fig. 2

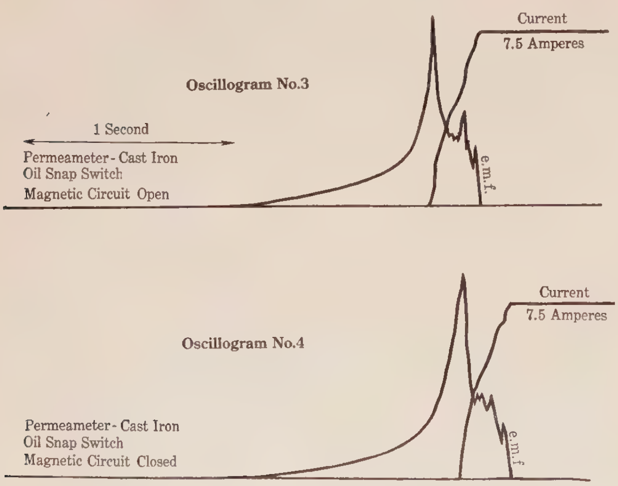

Fig. 3

Ballistic galvanometer readings were taken simultaneously with oscillograms 1 and 2, and were very erratic, as would be expected from the shape of the secondary voltage curve.

It was clearly evident that the circuit breaker did not give a quick clean break, and a 20-ampere snap switch immersed under oil was tried. The results with this switch are shown in Fig. 3, oscillograms 3 and 4. In 3 the magnetic circuit was open and in 4 it was closed. The time of interrupting the circuit was nearly the same in the two cases, 3 requiring 0.23 seconds and 4, 0.24 seconds. In oscillograms 3 and 4 there is only one pronounced peak of secondary e. m. f., but the secondary voltage rises to this peak in an irregular way. A study of these oscillograms shows also that the secondary e. m. f. continues to exist after the current has been interrupted. In fact, this continuation of e. m. f. after the cessation of the current lasts for about one second in all of the four oscillograms shown in Figs. 2 and 3.

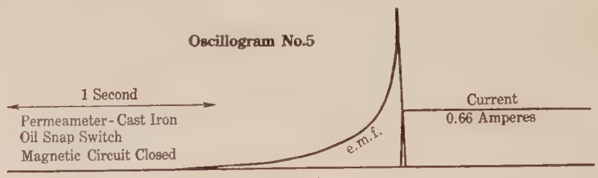

Fig. 4

In Fig. 4 oscillogram 5 is reproduced. This oscillogram was taken with a magnetizing current of 0.66 ampere through the solenoid of the cast-iron permeameter with a closed magnetic circuit and using the oil-break switch. It shows that the current is interrupted in about 0.02 seconds and also that the secondary e. m. f. continues for about one second after the magnetizing current ceases to flow. In other words, the secondary e. m. f. is maintained for about the same length of time irrespective of the current opened as found in oscillograms 1 to 4 inclusive.

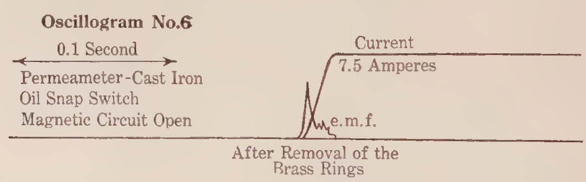

Fig. 5

These five oscillograms all show that the flux lags behind the magnetizing current that produces it. This lag was found to be due to the presence of eddy currents induced in the brass rings forming the ends of the spool supporting the magnetizing solenoid. This is conclusively proved by oscillogram 6, shown in Fig. 5. This oscillogram is taken with the cast-iron core permeameter with the brass rings removed. The oil-snap switch was used to break the magnetizing current and the magnetizing circuit was open. A study of the the oscillogram shows that the secondary voltage and current sink to zero practically simultaneously. The secondary e. m. f. builds up to a peak in an irregular

manner as before and then falls rapidly to zero. The total time that the secondary voltages continues is 0.02 seconds.

This series of six oscillograms brings out clearly the necessity of avoiding the presence of short-circuited paths in which eddy currents may be induced in permeameters. It also shows the superiority of the quick break switch operating under oil over the circuit breaker for opening the magnetizing current. The oil-break snap will open the circuit in less than 1/5 of the time required by the circuit breaker.

Two oscillograms were taken of opening the circuit under the same conditions except that in one the current was supplied by a 120-volt storage battery and in the other by a 10-volt battery. These oscillograms are very nearly identical. They show that it took a small fraction of a second longer, about one thousandth of a second as nearly as can be determined from comparing the oscillograms, to open 120-volt supply than the 10-volt supply.

Reversal of the Current

Before removing the brass ends from the cast-iron core permeameter, the problem of the reversal of the magnetizing current was investigated. In this work an ordinary double-pole, double-throw reversing switch, a special reversing switch that makes contact in the opposite direction before it opens the first circuit, and an oil-immersed snap reversing switch were tried. The special switch in its mid position short-circuits both the supply circuit and the permeameter winding. The oil-immersed reversing switch was a standard four-way snap switch such as is used in electric lighting circuits.

In the previous work the speed of a quick break under oil had been clearly demonstrated for opening the circuit in a very short space of time. It was, of course, realized that the problem involved in the reversal of the magnetizing current included the make as well as the break. It is, therefore, a question of the time constant of the circuit to a large degree. It was felt that this permeameter with the heavy damping, caused by the brass rings, was ideal to experiment with.

The results obtained with the three reversing switches are shown in Fig. 6. The current used was 0.66 amperes, and the magnetic circuit was closed. Oscillograms 7, 8 and 9 are for the double-pole, double-throw switch, the special switch, and the oil-reversing switch respectively. Oscillogram 7 shows that it takes considerable time to operate an ordinary double-pole, double-throw reversing switch of 180 deg. throw. The secondary e. m. f. sank to zero before contact was made in the opposite direction. Efforts to manually operate this switch at a high rate of speed were not successful. This type of switch is clearly unsuited for magnetic testing. Oscillograms 8 for the special switch, which has a throw of only about 15 degrees, shows clearly its superiority over the 180 deg. throw switch. The oil switch gave a much quicker break than the others, as expected. There is only one peak of secondary induced e. m. f. for both the special and the oil-reversing switches. All three oscillograms show the gradual building up of the current in the cast-iron core permeameter after its reversal. In all cases the secondary e. m. f. continues for several seconds before it sinks to a negligible value, for the special switch the time was 5 seconds and for the oil switch 3.9 seconds.

It is a well known fact that the theory of a ballistic galvanometer assumes that all of the charge passes through the galvanometer before it commences to deflect. Professor Laws has shown Laws-Electrical Measurements) that accurate results are possible with a ballistic galvanometer, provided the duration of the discharge is less than one twentieth of the galvanometer period.

It is apparent from oscillograms 7, 8, 9 and 10 that the largest factor influencing the time of reversal is the growth of the current. The use of a quick-break switch operating under oil will effectually solve the problem of opening the circuit in a very short interval of time.

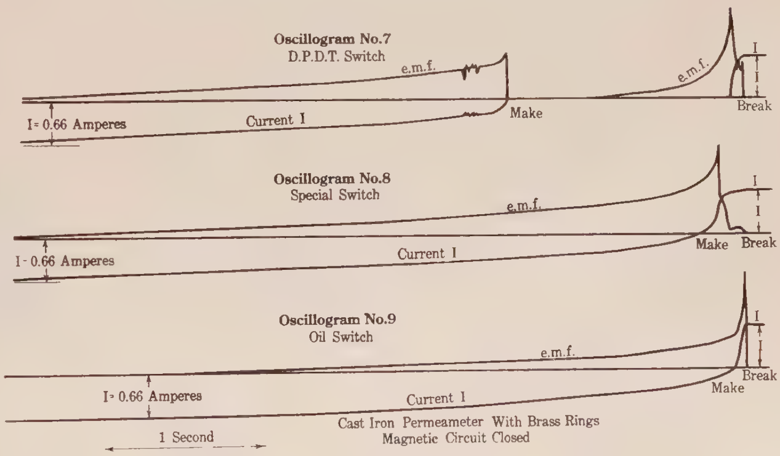

Fig. 6

Therefore, efforts were made to reduce the time constant of the circuit and to shorten the time required for the current to reestablish itself in the reverse direction. A number of schemes were tried.

Among these the effect of introducing a break in the iron of the magnetic circuit upon the time of reversal of the current was tried. Fig. 7, oscillogram 10, shows the effect produced by the introduction of two 1/16-in. gaps in the iron of the magnetic circuit. This oscillogram was taken with the special switch and 0.66 amperes of magnetizing current with the cast iron permeameter. In this case the secondary e. m. f. disappeared in 3.2 seconds as against 5 seconds without the gaps. With an open magnetic circuit the time fell to 1.8 seconds.

Another scheme of shortening the time of reversal of the current that was tried was to place condensers in parallel with the magnetizing solenoid of the permeameter, and neutralize the self induction of the winding.

Several arrangements were tried without success due to the production of current oscillotations in the circuit.

The method that met with the most success was to placing large inductances in series in the line between the source of supply and the special reversing switch, which does not open the initial circuit through the permeameter until it has closed the circuit in the opposite direction. As stated above, this special switch in its mid position short-circuits both the supply circuit and the permeameter winding. The low-voltage windings of a transformer were used for the inductance. Using this special reversing switch, the method reduced

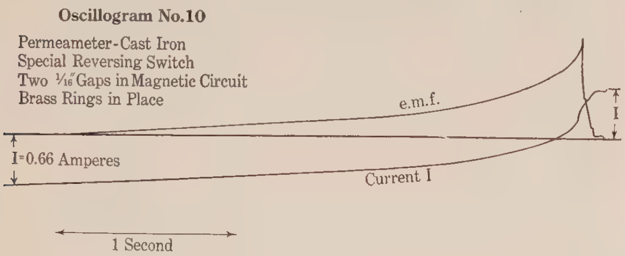

FIG. 7

the time of reversal about 40 per cent. The reason for this is that the inductance in the line tends to maintain the line current constant, and that the special reversing switch does not interrupt the line current, but simply reverses the current through the permeameter. The method of course failed to reduce the time of reversal when any type of switch was used that opened the first circuit; that is it opened the line current; before it closed the circuit in the opposite direction. This is due to the fact that in this case the extra inductance placed in the circuit is added to that of the permeameter windings and increases the time constant of the circuit.

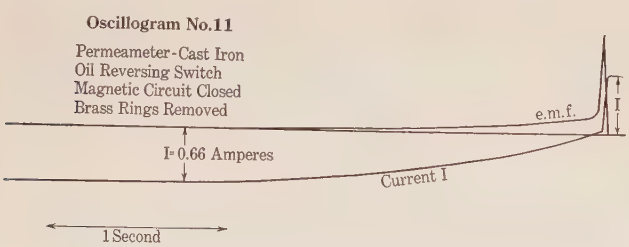

FIG. 8

In Fig. 8 oscillogram 11 shows the effect upon the time of reversal produced by removing the brass ends of the coils. Oscillogram 11 was taken with the magnetic circuit of the permeameter closed, and a magnetizing current of 0.66 amperes. The oil-reversing switch was used in taking this oscillogram. A study of this oscillogram shows that the secondary e. m. f. continues for 1.7 second, as against 3.9 seconds, shown in oscillogram 9, Fig. 6, taken under identical conditions, except as to the ends of the brass spool.

The investigation of the reversal of the current also brings out the importance of avoiding short-circuited paths in which eddy currents may be set up by the reversal of the magnetic flux.

SILICON STEEL PERMEAMETERS

A number of tests were made with these two permeameters. Two of the oscillograms, 12 and 13, which were taken under the same conditions are reproduced in Fig. 9. Oscillogram 12 is for the solid silicon steel core permeameter and 13 for the laminated silicon steel core. A study of these shows that it required 0.23 seconds to reverse the current in the solid core permeameter compared to 0.08 seconds to reverse the same number of ampere turns in the laminated-core permeameter. The oil-reversing switch was used in both cases and the magnetic circuits were closed. In both cases the secondary e. m. f. dropped to a negligible value by the time the reversal of the current was completed. This test brings out the superiority of the laminated-core permeameter as far as the time of reversal of the magnetizing current is concerned.

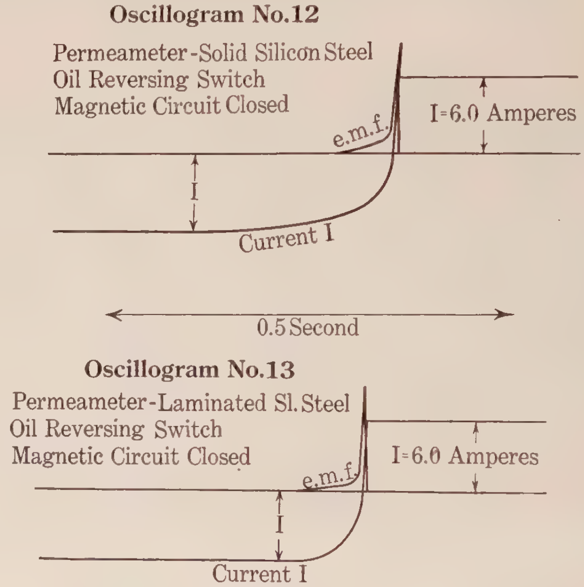

FIG. 9

CONCLUSIONS

The results of this investigation bring out clearly: *First*, the necessity of avoiding the presence of any unnecessary short-circuited path, which is cut by the flux of a permeameter. The frame upon which the coil for measuring the flux through the specimen is wound should be of such construction as to prevent the flow of eddy currents.

Second, that the use of a switch operating under oil will shorten the time of breaking the current.

Third, that the laminated-core type of permeameter will materially reduce the time required for the reversal of the current and thereby make the use of a short period ballistic galvanometer possible in magnetic testing. This will reduce the time required for a test.

The authors wish to thank Mr. H. C. Willis and Mr. W. C. Ball, postgraduate students in Electrical Engineering at The Johns Hopkins University, for their assistance in preparing this paper.

The Economic Development of a Step-by-Step Automatic Telephone Equipment

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Review of the Subject.—*Since Campbell published his paper in 1910, modifications have been made on the step-by-step telephone equipment. This paper covers a review of the economic development of this system with particular emphasis on the technical development in general. The material is grouped under development of circuits and trunking, mechanical design, manufacturing methods, maintenance improvements and possible future developments. Saving in equipment and trunks is considered under the switching selector repeater, director and frequency selecting connector while the reduction in maintenance cost is shown by the reduced number of troubles per line per month when comparing the newer developments with equipment installed fifteen years ago.*

TELEPHONY has together with the electric power industry undergone a tremendous development within the last fifteen years. The rapid advances made in electrical materials, the study and analysis of methods and means of manufacture and the contributions of pure science are finding application in the industry.

Since the inception of the telephone in 1876 the subscriber's needs and operating demands have increased constantly and definitely, tending to complicate the apparatus. Particularly is this true in the case of automatic telephony where the subscriber, because of the nature of the system, expects to obtain an answer from a called party in a minimum time and with the least mental and manual effort. On the other hand the

FIG. 1—SIMPLE STEP-BY-STEP SYSTEM

manufacturer has by the most approved and latest methods tried to improve the quality of the product and at the same time tried to make it more economical. Briefly stated the situation resolves itself into two main issues: (a) the increasing needs of the subscriber and operating company and (b) the reduction of cost of the equipment.

Without regard to the changed economic conditions of the country the subscriber's increasing needs from the start have forced the cost of the equipment up faster than the manufacturer could reduce the cost by redesign and methods. At the present time these needs are still of prime importance and still slightly overbalance the gain made by improvements and developments.

Because of its unit structure the step-by-step telephone system lends itself readily to an analysis of how the needs of the subscriber and operating company are met economically by the use of the latest developments. Each unit performs a definite function practically independently of the other units and consequently may be studied with regard to cost, performance, maintenance, life, and so forth without involving the rest of the equipment.

Inherently the system consists of a series of line switches, selectors, repeaters and connectors operated by a dial at the subscribers station. Campbell[1] in 1910 outlined the major parts and functions of the elementary step by step system. Fig. 1 shows the parts that constitute this system assigning to each part its proper place in the chain of equipment.

In order to consider the various phases of the development and the result obtained the subject will be considered with regard to the developments in design of circuits and trunking which represent the ideas to be carried into practise, mechanical design and materials which crystallize these ideas in actual mechanisms, manufacturing methods producing the mechanism in quantities, maintenance improvements or the performance in practise and possible future economic developments.

Developments in Design of Circuits and Trunking

During the past thirty years that the step-by-step system has been in use various developments have been made on the original idea advanced by Strowger. Naturally some of the early work was revolutionary during the time the apparatus was serving its apprenticeship. These changes may well be reviewed as early developments while the more recent progress is considered under the subject of later developments.

EARLY DEVELOPMENTS

All early exchanges were operated on the three-wire system, which in reality consisted of a two-wire system plus the ground circuit. The change from three-wire to a straight two-wire system, first introduced in 1907

To be presented at the Midwinter Convention of the A. I. E. E., Philadelphia, Pa., February 4-8, 1924.

1. A Modern Automatic Telephone Apparatus. W. Lee Campbell, TRANS. A. I. E. E., 1910, Vol. 29, p. 55.

came about largely by the possibilities offered by the two-wire system for purposes of station metering, pay station control, supervision and the like, besides simplifying the telephone wiring with resulting lower maintenance costs. Among other ailments, the three-wire system had the disadvantage of premature release in certain conditions in party line service. It required a good ground connection in the circuit when setting up a call. While in many cases an excellent ground connection is maintained, at every subscriber's station at the present time, be it manual or automatic, this is used for purposes of signaling and protection whereas early automatic stations used such a ground primarily for dialing.

The two-wire system was made possible largely by the adaptation of slow release relays. This type of relay has gradually been developed until it now finds a place on nearly all switches used in the system.

Machine ringing, although first used in manual exchanges, was applied to automatic service because its use resulted in shorter holding time of trunks besides relieving the subscriber from the additional burden of ringing the called subscriber's bell.

Later Developments

Mixed Number Systems. Although mixed number systems had been used in special cases the Columbus, Ohio installation illustrates the advisability of using such a system resulting in an economy of equipment. As mentioned in the introduction the simple system required a major switch for every digit dialed. In the case of the exchange mentioned a four-digit system was used until the growth of the system required additional equipment. By the addition of third selectors as required the system was expanded gradually. Fig. 2 indicates how the simple step-by-step system lends itself to future growth by the addition of but small amounts of equipment and no rearrangement of subscriber's numbers. If a proper traffic study has been made and the traffic development can be forecast with a fair measure of certainty, then the installation of the mixed number system is a real economic advantage; if, however, this information cannot be obtained the possible rearrangement of certain groups in case the system is installed may affect the advantage gained.

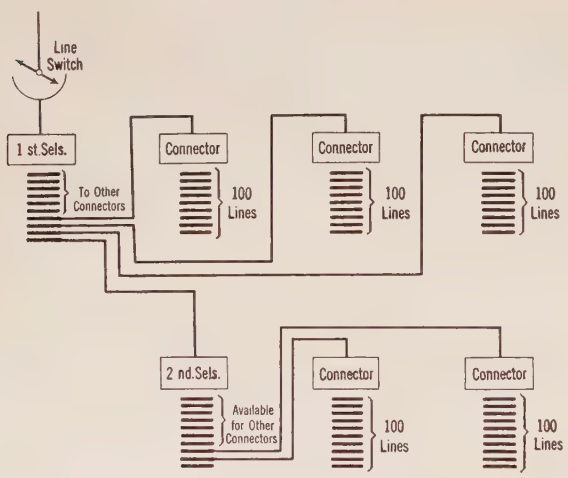

Fig. 2—Mixed Number System

Traffic Recorders. The study within recent years of traffic conditions by operating companies with a view toward the elimination of superfluous equipment, the addition of equipment where needed, the economic distribution of traffic and the economical number and arrangement of trunks, both local and inter-office, required that the group equipment be modified to allow the obtaining of this traffic data. Various traffic recording machines have been developed and find increasing application. Fig. 3 shows such a traffic recording machine in operation in an exchange. Numerous theoretical calculations have been made along this line and these machines are being used to obtain the practical substantiation of these formulas.

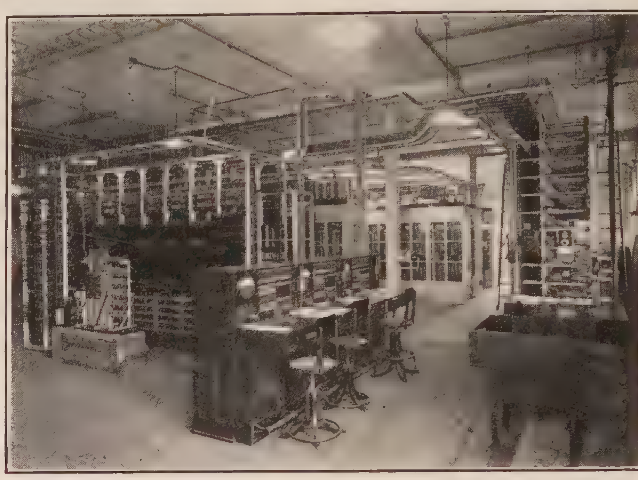

Fig. 3—Traffic Recording Machine in Operation in an Exchange

Line switches. Plunger type line switches on account of their preselecting nature are commonly used for primary line switches. The introduction of secondary line switches invariably effects a saving due to trunk efficiency wherever the traffic is normal. The development of the rotary line switch came about largely through efforts to make a self-contained unit. Because of its unit structure, that is, independence of common mechanism, compactness and reliability the rotary line switch lends itself admirably for secondary line switch duty.

Switching Selector Repeater. The development of the switching selector repeater was one of the milestones in recent years. This switch as its name implies is a unit combination of a repeater, selector and a discriminating device, intended to repeat impulses to the main office and at the same time to determine whether or not the call is going to or through the main office or whether it is intended for a local number. Eventually the number dialed will indicate to the switch whether or not the call terminates in the local or main office.

Just as soon as the proper combination of digits is dialed which determines that the call is not intended for the local office, the discriminating feature ceases to function and the switch continues to function simply as an impulse repeater. If, however, the call is intended for a local subscriber, the switch operates as a selector after the last digit of the discriminating part of the number and at the same time releases the trunk to the main office with its attached apparatus and leaves it

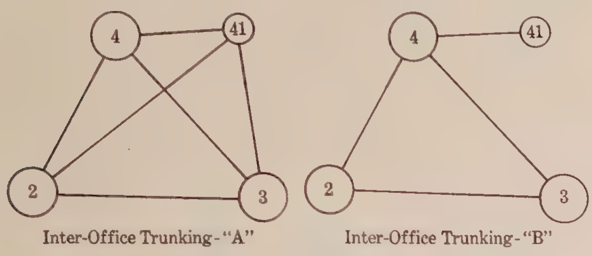

Fig. 4—Trunking to Sub-Office without and with Switching Selector Repeaters

available for other connections. The general method of operation consists in elevating and rotating the shafts of major switches simultaneously in the local and main offices and after the last discriminating digit releasing the switch or switches in the undesired office.

This device finds its greatest economic application in the case of the sub-office as shown in Fig. 4. In the simple step-by-step system inter-office trunks are required from each office to every other office in the

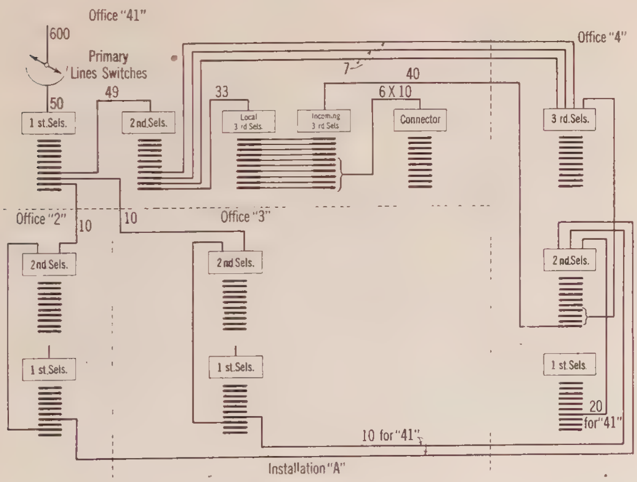

Fig. 5—Equipment Requirements in Sub-Office without Switching Selector Repeaters

system, but the use of the switching selector repeater requires trunks only to the main office nearest the sub-office.

The economy effected by the use of switching selector repeaters varies with the specific case and depends on the merits of the individual case. The additional inter-office trunks required largely determine and limit the saving. As an illustration of the equipment saving in the sub office, Fig. 5 and Fig. 6 show the arrangement of the equipment and trunks required in a simple system and a typical installation with switching selector repeaters.

As a basis of calculation let the traffic requirements rest on the following values, where $T\ C$ represent traffic units based on the busy hour traffic.

Office	to Office		Office	to Office	
41	41	12.84 T C	4	41	5.92 T C
41	4	5.92	3	41	2.96
41	2	2.96	2	41	2.96
41	3	2.96	41	41	12.84
Total originating		24.68 T C	Total incoming		24.68

The quantities of equipment are as follows:

	Installation A.	Installation B.
1st Selectors	50	0
2nd Selectors	49	0
3rd Selectors Local	33	50
3rd Selectors Incoming	40	40
Connectors	60	60
Outgoing Sec. Line Sw.	0	50

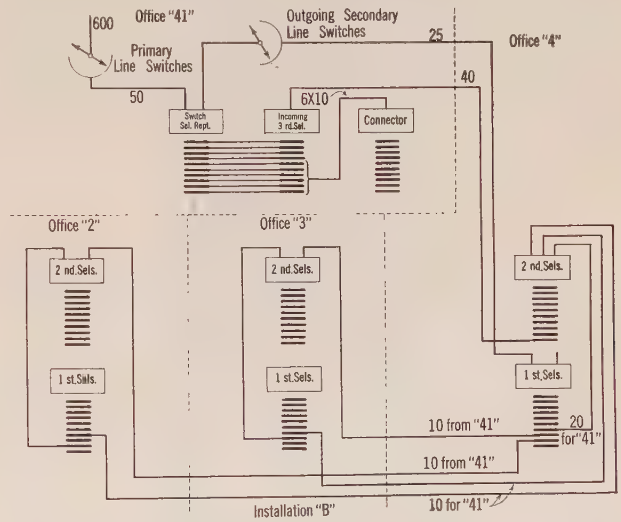

Fig. 6—Equipment Requirements in Sub-Office with Switching Selector Repeaters

Summed up in brief form installation *B* replaces 82 selectors with 50 line switches, the relative cost of the two complete, being in the ratio of three to one.

Frequency Selecting Connector. Another decided economic advance particularly in the case of the small community automatic exchange came about through the development and application of the frequency selecting connector. As shown in Fig. 7 the switch resembles the ordinary connector except for the addition of two relays and a minor switch, which selects the desired frequency.

Previous to the adoption of this switch party line service depended on a group of party line connectors the banks of which were multipled together and giving access to one hundred lines for each group. The group was taken from a first selector level and the desired frequency obtained from a level on a second selector. In the case of the frequency selecting connector each

connector selects the proper frequency. Since these connectors can be used indiscriminately for straight, four-party or ten-party line service they can be used on any board resulting in a saving of group equipment. This is very noticeable in the case of mixed service where the exchange is small and party line service predominates.

The Director. A very recent development adapting step-by-step equipment to large metropolitan areas where tandem offices and other complex trunking problems are encountered is the director. The standard equipment previously described makes it imperative to correlate the office number dialed with a certain and definite level on each of the major switches. Further,

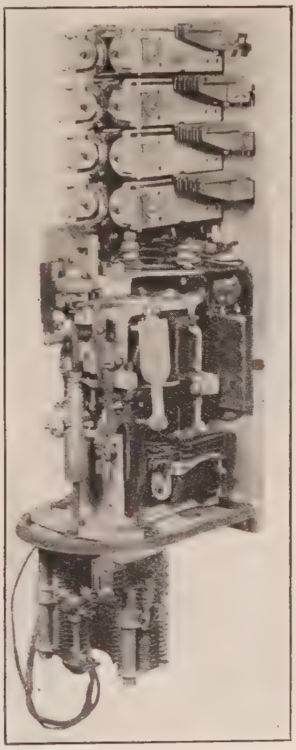

Fig. 7—Frequency Selecting Connector. Minor Switch Just Below Relay Group

in calling an office it may be necessary to pass through tandem offices each of which would require that the subscriber dial at least one digit. The director is an equipment inserted between the secondary line switch and the first selector to dissociate the numbering from the trunking scheme. It comes into play during the dialing of the number, it rearranges this number and directs the call over the most economical trunk route by any suitable combination of digits and is then disconnected re-establishing the usual through connection.

The actual apparatus as shown in Fig. 8 consists of a director selector, the director, a common impulse machine and a group of relays common to all directors. The director selector in the case of a three letter office code system is practically identical with a standard selector except for one additional relay, and functions to select one of a number of directors on the first digit called. It releases the director after the completion of the call but remains busy during the duration of the conversation.

The director Fig. 9, consists of an office code register, four numerical registers, register control, a cross connecting block, sender control switch and a group of relays. By dialing the second and third digits the office

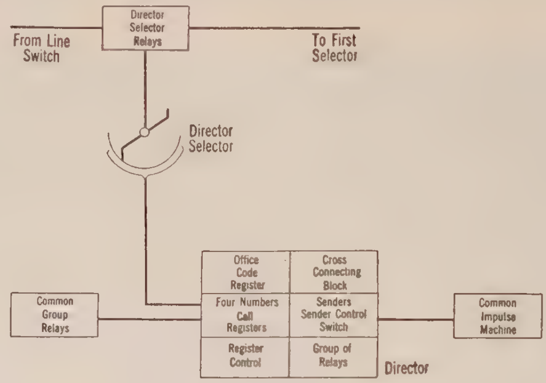

Fig. 8—Director System

code register can connect its four wipers to any one of one hundred sets of four bank contacts making one hundred possible offices available for this director. Since there are ten levels in the director selector this makes a possible one thousand offices available to the subscriber. The numerical register records the successive digits as they are sent in. In the meantime the sender starts to retransmit the number, but due to

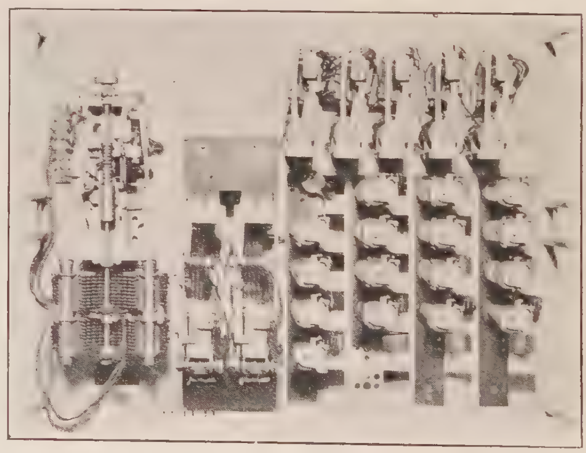

Fig. 9—Director

the arrangement of wiring on the cross connecting block which allows the number dialed in, to be converted into any other number of either more or less digits, the call is actually routed over a number combination most favorable to the various offices through which it passes. The common-impulse machine supplies the proper electrical impulse to propagate the call, while the relay equipment consisting of supervisory, and the like, is similar to that customarily in use.

As previously outlined the switching selector repeater when economically applied to a certain traffic area effects an economy of switches against a slightly increased number of inter-office trunks. The director on the other hand when applied to a large metropolitan area, and in general this is its only economic application, results in a saving of trunks, not only in the number of trunks used, but also in the efficient use of existing trunks.

For a particular case the use of the director reduces the number of second selectors required from 545 to 80 or a saving of 465 selectors. In this particular case the saving in selector equipment approximately counter balances the additional cost of director equipment. In larger metropolitan areas where the trunking is more complicated and where tandem operation is required, the saving in trunk groups will more than compensate for the cost of director equipment. This is especially true when two or more complete units of 10,000 lines are installed in one building.

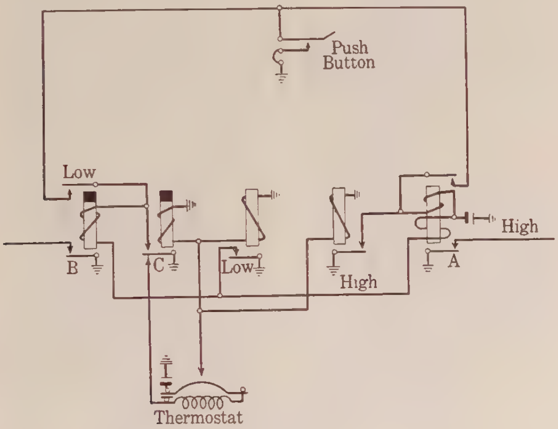

Fig. 10—Diagram of Voltage Limits Equipment

Voltage Control Apparatus. An interesting power development resulting incidentally in connection with the development of automatic telephony is the voltage control apparatus. Since it is desired to keep the battery voltage between 46 to 49 volts the voltage control apparatus must be extremely sensitive and at the same time sturdy enough to stand considerable abuse. The common form of high low-voltage control in the form of a meter element is not reliable, due to the light contact pressure resulting in poor contact particularly after a period of operation when the contacts are slightly pitted or dusty. The most recent device along this line consists of two relays margined to pull up on a voltage is excess of a certain value. Fig. 10 shows the general arrangement of the scheme. A test relay tests the line voltage intermittently, say four or five times per minute. In case the voltage is low no relay pulls up and the circuit condition causes a counter-cell to be cut out; if the voltage is normal one relay only pulls up causing no movement of the counter cell switch; in case the voltage is high the operation of both relays cause a circuit condition to be established which results in the cutting in of a counter cell. The specific application of this scheme is shown on the fifty-line private automatic exchange equipment. Fig. 11A. The two high and low operating relays may be seen in the lower right corner. Fig. 11B gives the front view of the board showing the battery-charging generator

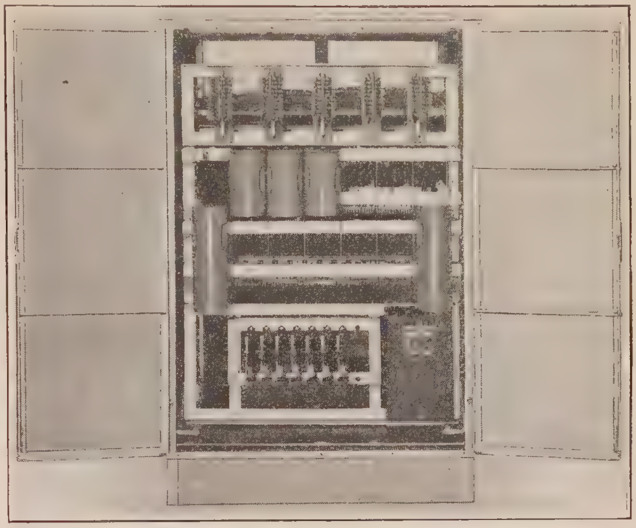

Fig. 11A—Fifty-Line Private Automatic Exchange.
Rear View showing Voltage Control Relays

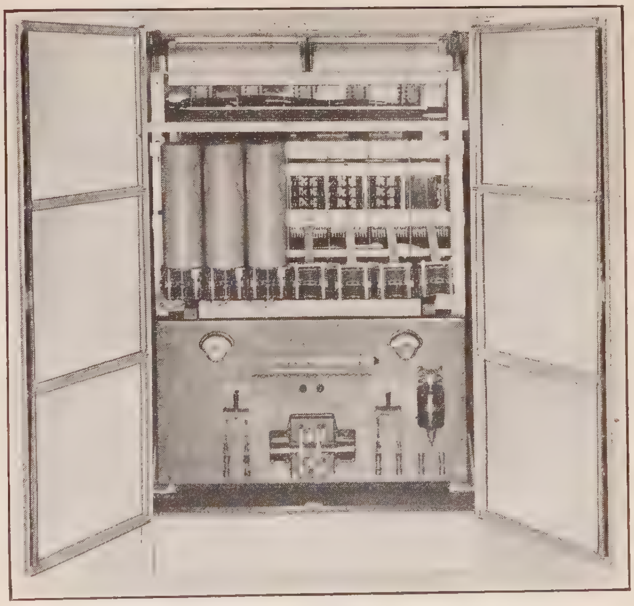

Fig. 11B—Fifty-Line Private Automatic Exchange.
Front View showing Motor Start Switch

start switch and the combination end cell and cut-off switch.

Incidental Developments. Many incidental developments were made during the last five to ten years. The rotary movement on the selector was changed from the common interrupting for a group of selector switches to the self interrupting and later to the relay controlled type.

Although this resulted in a slightly slower speed of hunting an idle trunk this was compensated by a positive stop on the first idle contact and uniformity of operation. Reverting-call switches, code ringing on community automatic exchanges, rotary connectors for private branch exchanges, zone metering, toll switching, measured service and many other parts of the equipment were perfected.

Mechanical Design and Materials

The development of circuits is closely allied with mechanical design and this in turn with materials. A typical case illustrating this point is that of the major switch which was changed in the case of the selector in 1910 and in case of the connector in 1918 from the side switch type to the present type. This change resulted in a switch controlling movements electrically by relay action, instead of mechanically. While the ensuing circuit was made slightly more complex the mechanical structure was materially simplified. The above change was brought about largely by the increasing use of the copper collar or slow acting relay, the time margins of which have been investigated with respect to their performance in step-by-step equipment.

The subsequent change in 1915 of the horizontal for the vertical type relay resulted in a switch which could

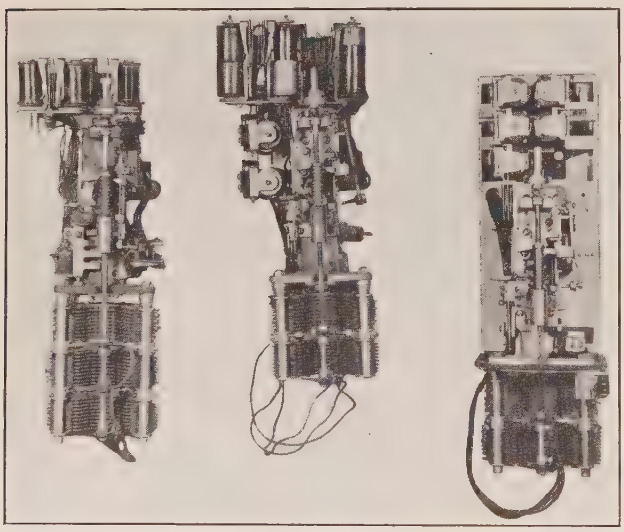

Fig. 12—Vertical and Horizontal Relay Type Selectors

be equipped with an individual dust cover. Fig. 12 shows the early styles of vertical relay switches together with the late horizontal relay type switch and Fig. 13 shows the latter type of switch equipped with the usual dust cover. In both the early and late switches the contacts and springs were mounted in a vertical position allowing any foreign matter as dust and small metal particles to pass through without becoming permanently lodged between the contacts.

Materials used in the construction of the relay and magnets have been improved similar to the changes made in magnetic circuits of the electrical power industry where low retentivity and high permeability are considered advantageous. Extensive tests have been made and are still in progress to find suitable magnetic materials. Various mechanical improvements have been made from time to time on the relay. The substitution of a hinge pin bearing for the pivot point type resulted in a relay with more uniform performance characteristics. This becomes apparent when it is

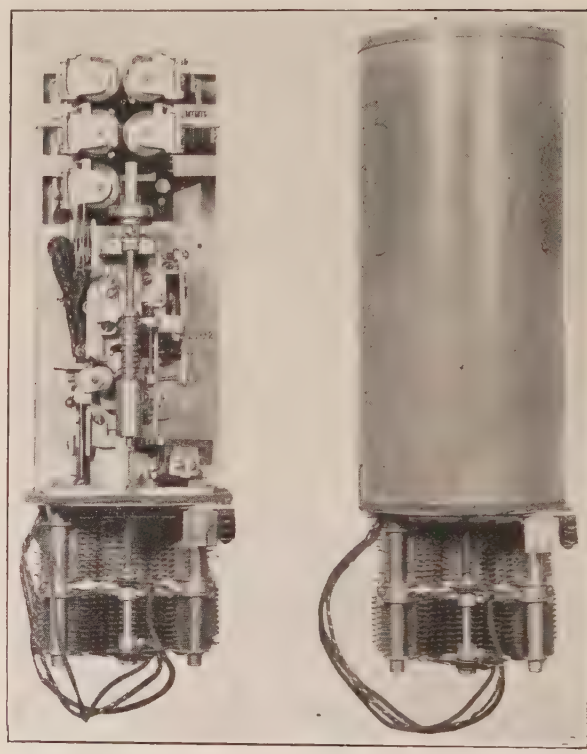

Fig. 13—Horizontal Relay Type Selector with Dust Cover

considered that the gap between the armature and the heel piece is on the order of 0.0015 in.

Adaptability of the same type relay for various circuit conditions further led to uniformity of design resulting in a type of relay which may be given any reasonable time characteristics by change in windings. A comparison of the horizontal type of equipment with the vertical type shows this uniformity of design in a striking manner.

The advent and use of high grade modern insulating materials did much toward the production of a higher grade relay and magnet. Formerly coils were made by winding the wire against the fiber heads, using paper insulation next to the core and the leads were brought out through holes in the fiber heads. Notwithstanding the fact that the negative side of the battery is connected to the coil permanently in most cases electrolysis still occurred between spool heads and the wire. Only by insulating the lead in wires between hard rubber washers, connecting them to termi-

nals on the head and winding the wire on a core insulated with empire cloth could this trouble be eliminated. Phenol fiber, bakelite and micarta are gradually replacing fiber and even though the first cost is higher, the resultant constancy of performance together with long life and freedom from electrolysis result in a more economical equipment.

Enamel-covered wire particularly in the small sizes of wire is finding increasing application in the general electrical engineering practise. While enameled wire is commonly used on relays and magnets in order to conserve space and to get the maximum number of ampere turns within a certain space the protection this wire offers against electrolysis and corrosion is one of its greatest advantages. The adoption in recent years of enamel-covered wire cable has done much toward the reduction of electrolysis and leakage between cable pairs within the office.

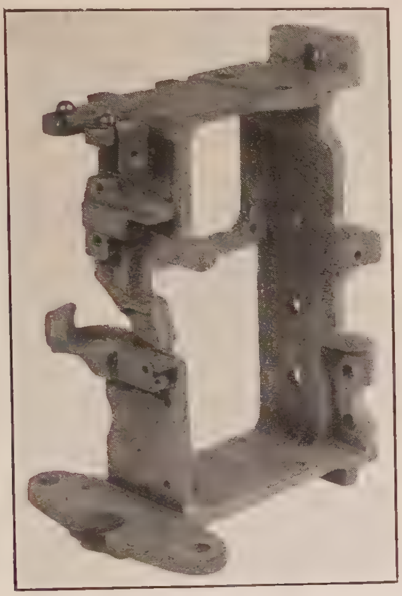

Fig. 14—Cast Iron Switch Frame

The various adjustments require that the switch frame does not change materially during the life of the frame. Numerous die cast metals have been tried, but have been found wanting in permanency. The cast iron frame Fig. 14 has gradually been developed and has been found extremely constant in retaining its shape. It may be noted at this point that this switch frame is the basis and foundation mechanically of all step-by-step major switches. The use of universal relays (mechanical) mounted on a standard plate together with the magnets mounted on the frame did much toward the standardization of this type of equipment. Major and minor parts are designed to be interchangeable allowing various special circuits to be used on standard equipment in case of some particular individual necessity.

Manufacturing Methods

Mechanical design as a rule must be closely allied with manufacturing methods. Although methods do not change frequently the universal use of the automobile did much toward the change in methods by the evolution of complex machinery for the finishing of small parts. Fig. 15 shows a multiple

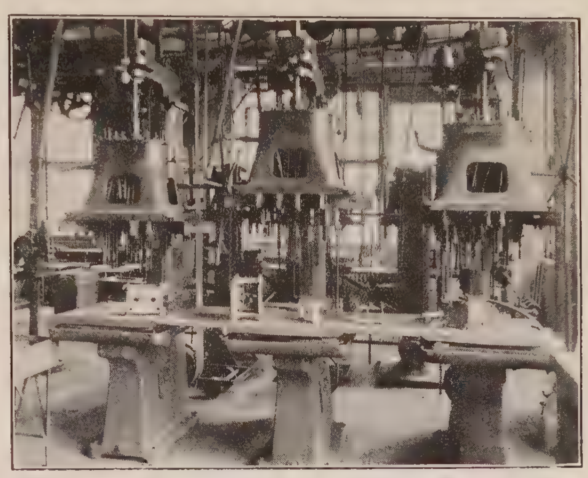

Fig. 15—Multiple Drill Press for Drilling Switch Frame

drill, such as is in common use in the drilling and tapping of holes in the switch frame mentioned above. By means of these multiple drills the frames are drilled quickly and accurately. Many other automatic and semi-automatic machines are used in the manufacture of a step-by-step equipment which are different from machines in customary use, such as contact welders,

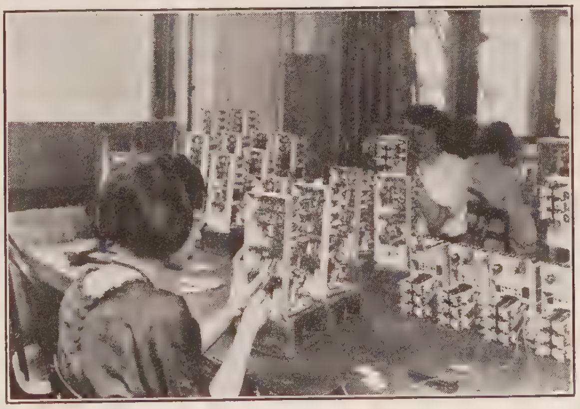

Fig. 16—Connector and Selector Wiring

either single or double contact, special wire braiding machines, and the like.

With regard to manual operations girls have been found to be excellent workers. In the wiring of major switches Fig. 16 one girl wires the switch completely using two tools. No single tool has been found which will perform as well or obtain as good results as the two

which are in use. The average time of wiring a selector complete is one half hour. This involves the skinning and attaching of 95 connections. In the standard connector there are 215 connections with approximately one hour and fifteen minutes required for wiring. Soldering these connections requires five minutes for a selector and twelve minutes for a connector. After wiring three or four switches from blue prints the prints are found unnecessary and all future wiring is done from memory. Squeezing and alineing fixtures Fig. 17 assure that the spring assemblies are in their correct positions horizontally and vertically and contribute materially toward the manufacture and assembly of these parts which in order to function uniformly must be very accurate.

An inspection and engineering inspection department maintain the product at a uniform standard and determine and set all standard adjustments. These

Fig. 17—Spring Alining Fixture

standard adjustments make the performance of the switches commercially uniform. The economic development of the step-by-step system is in a large measure due to the most approved methods of manufacture which allowed the full use of circuit development and mechanical design.

Maintenance Improvements

The standard parts with their definite tolerances and standard adjustments resulted in a decided uniformity of service while the proper routining keeps the equipment in first class condition. The change from three wire to two wire, from vertical to horizontal relay equipment and the introduction of dust covers gradually reduced the cost of maintenance per line per month. Fig. 18 gives some interesting comparative data regarding the number of these troubles. The main advantage, however, results in the use of less technical help in maintenance work due to the uniform construction and adjustment of the apparatus as mentioned above. By the use of a jack arrangement of mounting, the switches may be removed for repair in case of necessity and easily replaced by similar reserve switches.

Routining, that is the periodic testing of all switches and equipment, results in keeping the equipment in first class working order by discovering possible future troubles before they develop into factors which impair telephone service. This service together with the obtaining of service observation data provides an index

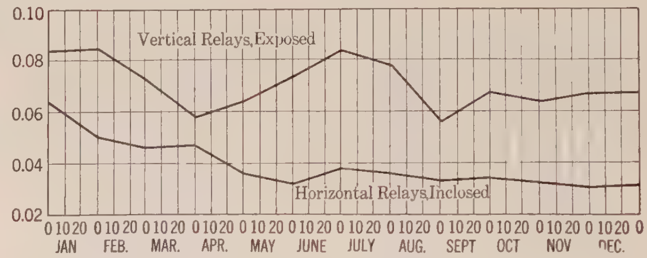

Fig. 18—Comparison of Two Specific Cases of Vertical and Horizontal Relay Equipment from Maintenance Standpoint.

Note Irregularity of Vertical Relay Equipment Curve while Horizontal Relay Equipment Curve Gradually Flattens out.

of the kind of service the equipment renders. Table I gives the tabulated results of service observations in various exchanges together with a final average obtained over a number of years. It is interesting to note that in the final average approximately 22.11 per cent of all lost calls are due to the subscribers whereas only 2.19 per cent are due to central office equipment. Fig. 19 shows the seasonal variation between the various causes contributing to lost calls.

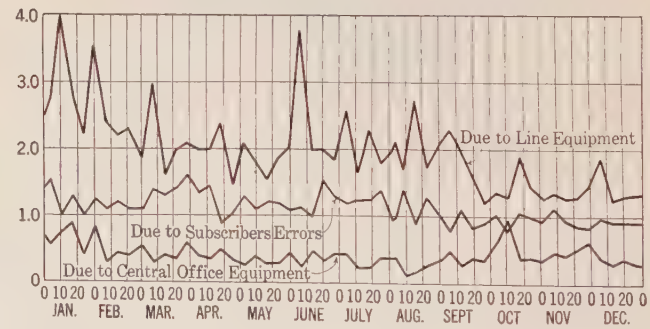

Fig. 19—Seasonal Variation of Per cent of Calls Lost due to Different Causes

In general it may be stated that all development in a measure reflects the maintenance viewpoint. The advances above mentioned on insulating materials, economy of equipment, economy of trunks, etc. invariably result in a lower maintenance cost.

Possible Future Economic Developments

The introduction of better materials as in the case of the relay has shifted the proportion of that much of the over-all cost as pertains to first cost and maintenance cost

from the latter to the former while at the same time reducing the sum of the two. By means of intensive circuit study and design coupled with mechanical simplicity the first cost may perhaps be lowered, while keeping the maintenance cost the same or even less.

Special materials are constantly developed. The selection of the proper materials with a knowledge of their capabilities and limitations offers unlimited possibilities in improving the performance and a possible reduction in over-all cost.

A definite value must be placed on lost calls, their significance in a trunking area and their evaluation against a definite amount of equipment and trunks, before equipment and inter-office trunks can be reduced to an economic balance in general. For instance the calculation of equipment on a lost call in one to one hundred leads to a materially reduced quantity of equipment over that calculated from a lost call in one to one thousand. The service on the other hand is not lowered in the same proportion. The cost of installation and maintenance vary very materially in different localities and in the same trunking area, therefore, the problem must be viewed in the light of the local situation. The study of local traffic conditions in any particular area by means of traffic recording apparatus to obtain definite and exact data is highly desirable.

The vacuum tube used as an amplifier offers possibilities in that a smaller current may be used and then amplified to the present values. Numerous advantages may accrue from such an arrangement as:

(a) High-resistance subscribers' loops of from 2000 to 3000 ohms.

(b) Replacement of 19 gage and smaller by gages in the neighborhood of 26 to 28 gage cables.

(c) Centralized office equipment in low value real estate areas.

(d) Use of high-resistance transmitters and receivers with possible gains of efficiency and clearer articulation.

Items (b) and (c) particularly indicate possibilities of effecting a saving, but as in the cases mentioned, these changes must depend on the merits of the individual case.

Conclusion

The step-by-step automatic telephone equipment has been developed largely along the lines of filling definite subscribers' and operating companies' needs. The system has undergone but minor changes but the equipment has been improved resulting in a lower maintenance cost and a longer life. Like the locomotive, the automobile and kindred pieces of mechanism, the step-by-step system has been standardized and its operation over a large number of years has been made uniform and reliable. No revolutionary future changes on the system appear imminent but the minor individual parts constituting that system will no doubt be modified to accomplish their specific circuit or mechanical function most economically.

SERVICE OBSERVATION TABLE

	Per cent of Originating Calls		Analysis of Uncompleted Originating Calls			Analysis of Failures		
Exchange	Completed	Uncompleted	Busy	Don't Answer	Failures	Subscribers Errors	Total Plant Trouble	Central Office Equipment Failures
A	79.41	20.59	8.92	8.67	3.00	1.35	1.65	1.32
B	74.06	25.94	11.65	9.92	4.37	2.95	1.42	1.07
C	78.66	21.34	10.96	6.73	3.65	2.19	1.46	1.18
D	74.13	25.87	10.43	8.37	7.07	4.45	2.62	2.10
E	74.60	25.40	9.68	8.20	7.52	5.14	2.38	2.04
F	79.37	20.63	7.74	7.52	5.40	3.63	1.77	1.05
G	69.66	30.34	11.15	9.91	9.28	5.20	4.08	2.75
Average	75.70	24.30	10.08	8.47	5.75	3.56	2.19	1.64

RADIO AND THE LIGHTNING HAZARD

In the past two years much has been said and written on the subject of the hazards of antennas used in radiophone receiving installations. It has been said that manufacturers of lightning arresters have in advertisements sought to convey to the minds of the untechnical public the idea that radiophone antennas are invariably a constant menace due to the probability that in time every wire elevated or suspended in space and connected at one end to the earth will be "struck" by lightning.

To remove this impression organizations promoting sales of radiophone broadcast receivers sponsored a campaign aiming to present to prospective purchasers statistics pointing to the conclusion that the risk is negligible. Representatives of some of these organizations felt that insurance companies, underwriters committees and inspection bureaus were overestimating the hazard, in the interest of bureaucracy and against the interest of those supplying the public's demand for equipment which could be installed in homes for the purpose of intercepting radiophone music, broadcast from centrally located stations.

The situation now is clearing as the public learns that the National Electric Code, recognized by fire insurance companies, specifies methods of wiring, including lightning protection, which should be followed where it is desired to minimize the risk of damage to life and property.

The larger manufacturers of radiophone equipment now include as a part of each complete outfit sold an approved lightning arrester, usually of the vacuum type.

Brush Mounting as a Factor of Satisfactory Operation

BY PHILIP CHAPIN JONES

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Review of the Subject.—*That the brush is an ever present source of trouble on rotating electrical machinery is evidenced by the back numbers of our technical periodicals which are replete with innumerable articles on the subject. These articles cover practically all problems of material and application excepting that of the geometrical design. It is this phase of the subject that the following paper attempts to give.*

Undoubtedly these factors of geometrical design are known as they are readily discovered; their relations are relatively simple, but so far as I have been able to find they have not been published.

The facts brought out by the following paper are: First, that the upper angle of the brush is a function of the lower angle and the coefficient of friction between the brush and the commutator, second, that the lower angle is a function of the pressure desired against the holder, and third, that the trailing brush has little to justify its use. These three conclusions are based on a design which eliminates a resultant moment acting on the brush which would tend to make it bind in the holder.

* * * * *

If the electrical engineer responsible for the maintenance of rotating electrical machinery is of an inquiring turn of mind he will sooner or later confront the question of brush design. The brush is one of those things which, in itself of minor importance, can so often be the seat of serious trouble. The selection of the proper brush is dependent on two groups of factors, brush quality and brush design. Relating to quality, there is quite a mass of available information largely in the publications of the various brush manufacturers. Density, hardness, conductivity, and coefficient of friction are tabulated for all the different grades and with the help of suggestions from the manufacturers proper selection is not difficult. In regard to the design of the brush and its position relative to the holder and commutator there is very little information extant that I have been able to find. It is in an effort to relieve this situation that the following brief outline of the essentials of brush design is written.

The function of the brush is to conduct current between a stationary lead and the moving commutator. The resistance of the contact between brush and commutator is proportional to the pressure perpendicular to the plane of contact. The amount of heating at the contact and the amount of current per unit area of contact that the brush can safely carry are proportional to this resistance and therefore the foremost problem of brush design is to keep the correct pressure on the contact surface at all times.

There are, in general, four forces acting on the brush: First, the longitudinal pressure of the brush spring; second, the reaction pressure of the commutator; third, the force of friction on the commutator which tends to move the brush parallel to its plane of contact; and fourth, the resulting side pressure of the brush holder. (Although the weight of the brush itself acts in different directions depending on the relative position of the brush on the commutator, it is neglected because in general it is small in comparison to the other forces acting.) These four forces are shown diagrammatically in Fig. 1. The forces shown are the resultant forces acting on the center of the various brush faces. P is the contact force with which we are primarily concerned, and T is the inwardly acting force of the brush spring—the only force that can be varied at will. The force of the holder against the brush is shown as H. It might, of course, be on either side of the brush. F is the force of friction and is equal to the coefficient of friction (f) of the brush on the commutator, multiplied by the contact force P. ($F = f\,P$). Since the coefficient (f) is given for various grades of brushes, the total force F can be eliminated as an unknown quantity, leaving only the other three forces, T, H and P, to be dealt with.

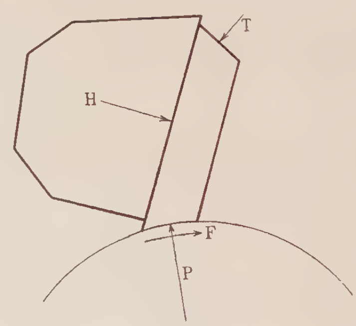

Fig. 1

Fig. 2 again shows the brush of Fig. 1 with the addition of all the critical angles marked as well as the forces. There are only three primary, independent angles — ψ, α and β. Thus the problem of brush design is to select the values for these three angles which will most effectively keep the contact force P at the desired value under all conditions.

The main obstacle with which we have to contend is friction between the brush and the brush holder which prevents free movement of the brush and thus causes variations in the contact force P. The brush is constantly wearing along the surface of contact and in order that the contact force P may be constant, the brush must be able to move freely outward as well as inward, so that it may follow any irregularities in the

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commutator. The forces preventing a free movement in the inward and outward direction perpendicular to the line H are friction against the brush holder, which is proportional to the side thrust H, and a possible binding of the brush in the holder when the resultant force H does not act at the center of the holder as shown, but above or below this point. This tends to cause the holder to cut into the brush at the bottom or top and thus lock it in one position.

To progress one step further, it becomes evident that

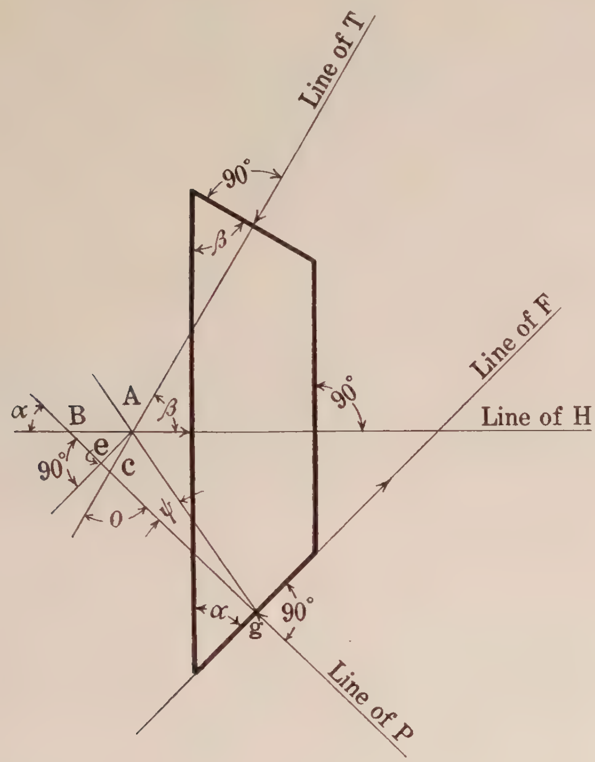

FIG. 2

correct brush design will consist in so selecting the three fundamental angles that the side thrust H not only acts at the center of the holder, to prevent binding, but is as small in absolute value as can safely be obtained with the object of minimizing the friction to radial motion.

An analysis of these forces and angles—given in the appendix—brings out the fact that there is only one independent variable, the lower brush angle α. For any value of α, the upper brush angle β, in order to prevent binding of the brush in the holder, must have a definite corresponding value represented by the expression $\beta = \alpha + \tan^{-1} f$.

Observing this requirement and keeping the contact pressure, P, constant at the desired value, the side thrust H varies as a complex function of α. The pressure of the brush spring, T, need not be changed in order to maintain the contact pressure (P) constant as α varies. (See Fig. 5)

To minimize friction of the brush against the holder it is desirable to hold the side thrust as small as possible. With a trailing brush this side thrust can never be less than ½ the contact pressure so that unless a condition exists that makes this relatively large side thrust necessary there is little excuse for the use of the trailing brush. Our natural tendency is to use the trailing position. We know if we pushed a stick along the sidewalk ahead of us it would catch, chatter, and altogether behave unmanageably, while if we trailed it, all would be well. In the case of the brush and commutator we are dealing with as nearly perfectly smooth surfaces as can be obtained so that the cases are not at all parallel. As is quite often the case our first impression is in error. Mathematical analysis reveals the true situation and unmistakably endorses the leading brush.

The ideal condition would be to make the side thrust zero. This would require a box-type holder with the brush run in the leading position. The lower brush angle would then have to be about 75 deg. and the upper brush angle 90 deg. For reversing motors—running as much in one direction as in the other—ideal conditions can never be attained and some compromise must be accepted.

APPENDIX

To arrive at the correct relations between the various forces and angles connected with the brush it is best to treat it as a problem in statics and to take moments of the forces acting around the intersection of T and H. Calling the arm of the force P equal to L_p and that of F, L_f gives the following: $P \times L_p = F \times L_f$ and as $F = f\,P$ then, $P \times L_p = f\,P \times L_f$ or $f = L_p/L_f$. It is evident that $L_p/L_f = \tan\psi$ whence it follows that,

$$f = \tan\psi \qquad (1)$$

The relation just indicated $f = \tan\psi$ must hold not only when the brush is new but also as it wears down to

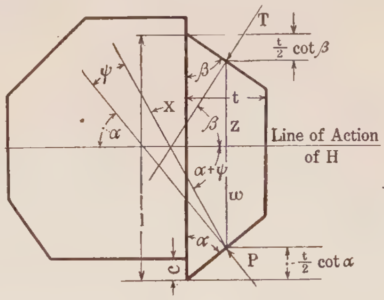

FIG. 3

its shortest length. To bring this about the intersection of the lines of action of T and H must always be on the line X which is one side of the angle ψ, and H must always be half way between the top of the brush and the bottom of the brush holder. With these requirements in mind it develops that, referring to Fig. 3

$$w \cot(\alpha + \psi) = z \cot\beta$$

where $w = [\,(1 - c)/2 + c] - (t \cot\alpha)/2 = 1/2\,(1 + c - t\cot\alpha)$

and $z = (1 - c)/2 - (t\cot\beta)/2 = 1/2\,(1 - c - t\cot\beta)$

Substituting these values of w and z in the above equation gives:

$$\cot(\alpha + \psi) = \frac{l - c - t\cot\beta}{l + c - t\cot\alpha}\cot\beta \qquad (2)$$

Now c can be made any value desired as part of the brush holder design. It should of course be quite small. If c is made of such a value that

$$\cot\beta = \cot(\alpha + \psi) \qquad (3)$$

then $1 - c - t\cot\beta = 1 + c - t\cot\alpha$

and $c = (t\cot\alpha - t\cot\beta)/2 = t/2\,(\cot\alpha - \cot\beta)$

$= t/2\,[\cot\alpha - \cot(\alpha + \psi)]$

An idea of the magnitude of c thus obtained may be had by taking $\alpha = 60$ deg. and $\psi = 15$ deg. and $t = 1/2''$ which gives $c = 1/4\,(0.577 - 0.268) = 0.077$ inch.

The great advantage of taking c of this value is that it gives the very simple relation between α, β and ψ of

$$\beta = \alpha + \psi \qquad (4)$$

This enormously simplifies the problem. The value of ψ is known as it is $\tan^{-1} f$. Thus the only angle to be determined is α whence β will follow from equation (4).

The effect of changing α is to change the relative values of H, T and P. The best method of determining the most satisfactory value of α then is to plot the relations between these quantities against α. As P is the pressure that directly affects the problem it will be best to plot the two ratios of H/P and T/P against values of α.

To obtain these values advantage is taken of the fact that as the brush is stationary the resultant of all forces acting on it is zero. Resolving all forces into tangential and radial components and equating each group to zero gives, for radial forces (parallel to P)

$$P - H\cos\alpha - T\cos\odot = 0$$

where $\odot = 180 - (\alpha + \beta)$ (5)

and for tangential forces (parallel to F)

$$F = H\sin\alpha - T\sin\odot = 0 \qquad (6)$$

From (5), $H = (P - T\cos\odot)/\cos\alpha$ and from (6)

$$H = (T\sin\odot - fP)/\sin\alpha$$

and equating these two values of H gives

$$(P - T\cos\odot)\tan\alpha = T\sin\odot - fP$$

whence may be deduced

$$T/P = (\tan\alpha + f)/(\sin\odot + \cos\odot\tan\alpha) \qquad (7)$$

Returning to equations (5) and (6) and solving for T and equating as was done for H gives:

$$H/P = (\tan\odot - f)/(\sin\alpha + \cos\alpha\tan\odot)$$

These values, it will be evident from a glance at Fig. 2, were obtained by considering a brush running in the leading position, *i. e.* with the direction of the commutator motion such as to tend to push the brush away from the holder. Before plotting these values therefore it will be well to examine the brush in the trailing position (commutator motion tending to force the brush against the holder) as shown in Fig. 4.

It will at once be evident that the same relation between f and ψ holds here as it does for leading brushes,

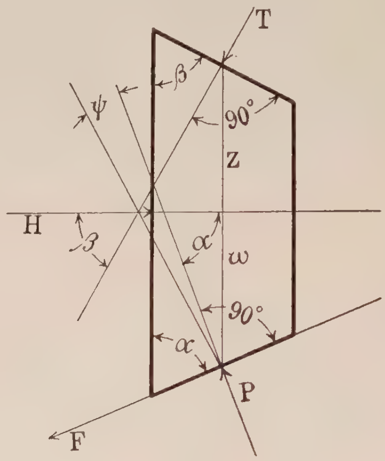

Fig. 4

i. e., $\tan\psi = f$. Here, however, ψ is on the opposite side of P. Thus ψ is always on the side of P toward the direction of F. In order, however, to use the same value for c as before we must have the relation cot

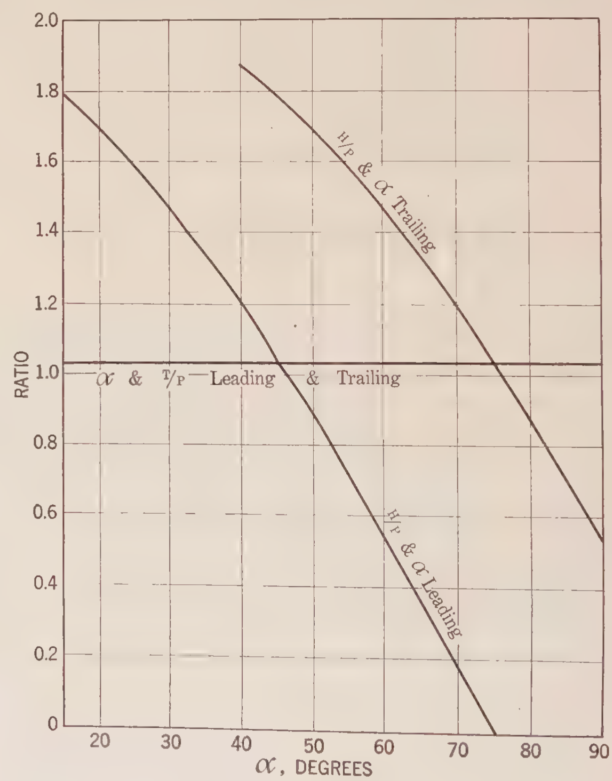

Fig. 5—Brush Data

$f = 0.268$

$(\alpha - \psi)$ equals $\cot\beta$ or $\alpha - \psi = \beta$. This is exactly the same equation as (4) with ψ taken as a negative angle. This relation will be found to hold throughout. All equations for leading brushes will hold for trailing

brushes if $-\psi$ is substituted for $+\psi$. As the tangent of a negative angle is negative f will also have to be considered as negative as $f = \tan\psi$.

This gives the two fundamental equations for trailing brushes as:

$$T/P = (\tan\alpha - f)/(\sin\odot + \cos\odot\tan\alpha) \qquad \textbf{(9)}$$

$$H/P = (\tan\odot + f)/(\sin\alpha + \cos\alpha\tan\odot) \qquad \textbf{(10)}$$

In making a plot some value of f will have to be assumed. The entire range of the coefficient of friction for different grades of brushes runs from perhaps 0.14 to possibly as high as 0.40. An average value would be in the neighborhood of 0.268 which gives 15 deg. as the value of ψ. For this value of f the curves of H/P and T/P are shown in Fig. 5. Inasmuch as no great accuracy of adjustment can be maintained in brush settings the curves shown are sufficiently accurate for all ordinary values of f.

Modification of Polyphase Induction Motor Performance by Introduction of e. m. f. in Secondary

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Review of the Subject.—*The possibility of obtaining speed adjustment and power factor correction of induction motors by impressing an e. m. f. on the rotor is a subject which has attracted considerable attention in recent years.*

As compared with the straight polyphase induction motor, the graphical treatment in this case becomes much more involved, if reasonable account is to be taken of all the phenomena. The analytical treatment of the polyphase induction motor is, however, readily extended to the case when an e. m. f. is impressed on the rotor.

There appears to be a general impression that in deriving formulas analytically the usual method based on the rotating magnetic field theory is no longer suitable when a voltage is impressed on the rotor, but that it is preferable to resolve the induced e. m. f. in the rotor into two components. This paper is an attempt to show that not only is the rotating field theory still applicable, but that the results can probably be obtained most readily by means of it.

It is well known that the insertion of a resistance in the secondary of a wound-rotor induction motor produces a drooping speed torque characteristic, the speed reduction at any torque being nearly proportional to the increase in secondary resistance. As frequently pointed out, the induction motor in this respect behaves like a shunt or lightly compounded direct-current motor with a resistance in the armature circuit. In both cases the reduction in speed is caused by a voltage being consumed in the resistance, the counter e. m. f. being equal to the $I\,R$ drop and in opposite direction to that in which the current is flowing.

This analogy is often extended to the case where an e. m. f. other than the counter e. m. f. of a resistance is employed to obtain variations in speed. Thus the e. m. f. generated by an auxiliary machine in series with the armature of a direct-current motor lowers the motor speed if in the same direction as the voltage generated by motor armature, and therefore in opposition to the line voltage, while it raises the motor speed if in opposite direction to the motor counter e. m. f. and in same direction as the line voltage. When, by analogy, these facts are applied to the induction motor, the inference is that a voltage inserted in the secondary in phase with the secondary induced voltage lowers the speed, and an e. m. f. in opposition to the induced voltage raises the speed of the motor.

Although misleading, this conception appears to be generally accepted, as reference to text books will show. For example, on page 56 of Steinmetz' "Theory and Calculation of Electrical Apparatus" is the following statement—"If, however, the voltage is inserted in phase with the secondary induced voltage of the induction machine, it has no effect on the power factor, but merely lowers the speed of the motor if in phase, raises it if in opposition to the secondary induced voltage of the induction machine, etc." Also, on page 322—"A rotor e. m. f. in opposition to the stator e. m. f. reduces, in phase with the stator e. m. f. increases the free-running speed of the motor." As will be pointed out later, the equations (**78**) and (**79**), on page 320, likewise appear to be misleading to the same extent.

In comparing the operation of the induction motor with that of a direct-current shunt motor, there are some differences, which generally seem to be overlooked. The direct-current armature develops a torque when the current flows in opposite direction to the e. m. f. induced in it, and its induced e. m. f. is zero at standstill and a maximum, that is approximately equal to the line voltage, when running at full speed.

The conditions are quite different in the rotor of an induction motor. In the range of speed from standstill to synchronism it is the component of secondary current in phase with the secondary induced voltage which produces torque, and the induced voltage is a maximum at standstill and zero at synchronism or full speed. In both the d-c. armature and the induction motor

rotor an inserted e. m. f. tending to increase the torque-producing current raises the speed and vice versa. Herefrom it follows that the effect of an inserted e. m. f. in the induction motor secondary is precisely the reverse of the above quotation from Steinmetz' book. That is, if in phase with the seconary induced volts, it raises the speed, and if in opposition, it lowers the speed. Above synchronism certain qualifications, which will be pointed out later, should be made when speaking of the inserted voltage as being in phase or in opposition to the induced voltage.

A reference to the diagram in Fig. 1 may be of assistance in illustrating the above.

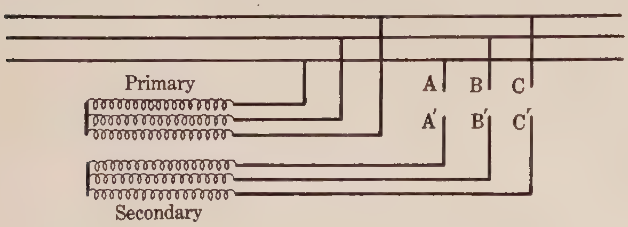

Fig. 1

Assume that the rotor winding and leads are symmetrical with reference to the primary, and that the ratio of transformation is 1 to 1. At standstill, with the secondary open-circuited, the induced voltage is approximately equal and opposite to the impressed voltage. If, then, the secondary leads A', B' and C' are connected to the line terminals A, B and C respectively, the only current that would flow in the secondary is a part of the primary exciting current and no torque would be developed. The free-running speed of the motor has therefore in that case been reduced to zero.

Let the ratio of transformation be changed to obtain an effect equivalent to reduction of the voltage impressed on the rotor to say one-half of full voltage. Sufficient energy current will then flow in the rotor to develop torque, and if the symmetrical relation between primary and secondary is maintained by some means, such as a commutator, and the motor is running light, it will speed up until the induced voltage has been reduced to approximate equality with the impressed voltage. The secondary induced and impressed voltages, being approximately equal and opposite, will cause no torque producing current to flow at this speed, which in that case is the free running speed and is nearly half way between standstill and synchronism.

On the other hand, assume an e. m. f. in phase with the secondary induced voltage to be impressed on the rotor circuits. There is then obviously no tendency to reduce the torque to zero at any speed below synchronism. Although the induced voltage is zero at synchronism, there is a torque, because the inserted voltage maintains a torque-producing current and the rotor continues to accelerate. As the rotor speeds up above synchronism, the secondary induced voltage increases in magnitude and has changed sign, and is therefore in opposition to the impressed voltage. Manifestly, the motor will speed up until the induced and inserted voltages are of approximate equality and the secondary current and torque reduced to zero. Because of the fact that the secondary induced e. m. f. changes its phase angle through 180 degrees above synchronism, it must be understood that when speaking of the inserted e. m. f. as being in phase with or in opposition to the induced e. m. f., it is the phase relations below synchronism that are referred to.

As discussed in numerous publications, a commutator is usually employed to change the line frequency to correspond to the frequency of induced volts at all speeds. It appears to be the general impression that under these conditions the well known method of studying induction motor phenomena by means of rotating magnetic fields is no longer suitable, but that it is preferable to separate the resultant secondary induced e. m. f. into two components, the transformer e. m. f. induced by the alternating magnetic flux and the rotational e. m. f. induced by rotation of the secondary conductors in the magnetic field. This needlessly complicates the derivation of the formulas and obscures the physical conception as the rotating field method lends itself most readily to an analysis of the phenomena involved.

Thus consider a polyphase induction motor so arranged that line voltage can be impressed on its rotor through a ratio of transformation c, and a phase displacement of ϕ radians. Also assume that by some means, such as shifting of brushes on a commutator, the rotor currents maintain a fixed displacement of θ radians in positive direction from the stator currents. The conditions then differ from the ordinary induction motor in that the voltage induced in the primary by the secondary current is advanced θ radians in phase, while the voltage induced in the secondary by the primary current is retarded θ radians, also the sum of the secondary voltages, instead of being equal to zero, is equal to $c\,E$, where E is equal to the line voltage in magnitude and displaced ϕ radians therefrom in phase.

As is well known to all familiar with complex numbers, multiplication of a vector by $\epsilon^{j\theta}$ advances its phase angle θ radians, and multiplication by $\epsilon^{-j\theta}$ retards its phase angle θ radians. Expressed in their horizontal and vertical components,

$$\epsilon^{j\theta} = \cos\theta + j\sin\theta \quad \epsilon^{-j\theta} = \cos\theta - j\sin\theta$$

Using the customary notation of motor constants, let

Z_m = Mutual-inductive impedance

Z_0 = Primary self-inductive impedance

Z_1 = Secondary self-inductive impedance

The e. m. f. induced in the primary by the primary current I_0 then is $(Z_m + Z_0)\,I_0$, and by the secondary current I_1 is $Z_m\,\epsilon^{j\theta}\,I_1$. The e. m. f. induced in the secondary by the primary current is $s\,Z_m\,\epsilon^{-j\theta}\,I_0$ and

by the secondary current $(s Z_m + Z_1) I_1$ hence the e. m. f. equations of the primary and secondary are, where s = slip

$$(Z_m + Z_0) I_0 + Z_m \epsilon^{j\theta} I_1 = E \quad (1)$$

$$s Z_m \epsilon^{-j\theta} I_0 + (s Z_m + Z_1) I_1 = c E \epsilon^{j\phi} \quad (2)$$

Solving these equations we have

$$I_0 = \frac{E [(s Z_m + Z_1) - c Z_m \epsilon^{j(\theta + \phi)}]}{s Z_m Z_0 + Z_m Z_1 + Z_0 Z_1} \quad (3)$$

$$I_1 = - \frac{E [s Z_m \epsilon^{-j\theta} - c \epsilon^{j\phi} (Z_m + Z_0)]}{s Z_m Z_0 + Z_m Z_1 + Z_0 Z_1} \quad (4)$$

If the voltage impressed on the rotor is in phase with the line voltage, ϕ is equal to zero, and the formulas reduce to

$$I_0 = \frac{E [(s - c \epsilon^{j\theta}) Z_m + Z_1]}{s Z_m Z_0 + Z_m Z_1 + Z_0 Z_1} \quad (5)$$

$$I_1 = - \frac{E [(s \epsilon^{-j\theta} - c) Z_m - c Z_0]}{s Z_m Z_0 + Z_m Z_1 + Z_0 Z_1} \quad (6)$$

Noting that δ and σ in equations (78) and (79) on page 320 of Steinmetz' book already referred to are respectively equal to $\epsilon^{j\theta}$ and $\epsilon^{-j\theta}$, it will be seen that the equations (5) and (6) are identical with his, except for signs. It may therefore be of interest to compare his formulas with the above in a special case, where I_0 and I_1 can readily be approximated directly from physical considerations. For example, let $s = 1$, $c = 1$, $\theta = 0$ and $Z_0 = Z_1$. The conditions are then precisely the same as discussed under diagram in Fig. 1, that is the rotor is standing still and the induced voltage is practically equal and opposite to the impressed voltage. Little current is therefore expected to flow in the primary and secondary windings as they are in parallel on the same magnetic core and magnetize the core in the same direction. Equations (5) and (6) then reduce to

$$I_0 = \frac{E}{2 Z_m + Z_1} \qquad I_1 = \frac{E}{2 Z_m + Z_0}$$

That is, primary and secondary circuits each take half the magnetizing current from the line, which was to be expected. Steinmetz' formulas in that case reduce to

$$I_0 = E/Z_1, \qquad I_1 = E/Z_0$$

That is, primary and secondary currents are limited by the self-inductive-impedances only, and are approximately equal to twice the normal locked currents with the secondary short-circuited. Manifestly, these are the currents which would flow if the secondary impressed voltage is in phase with the secondary induced voltage and in opposition to the line, as the primary and secondary magneto-motive forces are then in opposition and neutralize each other. Formulas (78) and (79) do not, therefore, appear to agree as well with physical conditions as the formuias (5) and (6) above, which were derived much more simply and directly on basis of the voltages induced by the primary and secondary rotating magnetic fields without being complicated by transformer and rotational voltages.

The line current is obviously equal to the vector sum of I_0 and $c I_1$. The torque and power are readily obtained from I_0 and I_1 as follows. The magnetizing current $I_{00} = I_0 + I_1 \epsilon^{j\theta}$

$$I_{00} = \frac{E (Z_1 + c Z_0) \epsilon^{j\theta}}{s Z_m Z_0 + Z_m Z_1 + Z_0 Z_1} \quad (7)$$

The secondary induced volts at full frequency is

$$e = I_{00} X_m \epsilon^{-j \left(\frac{\pi}{2} + \psi\right)} \quad (8)$$

Where X_m is the mutual reactance and ψ the angle of hysteretic advance.

Torque per circuit (synchronous watts)

where ω is the phase angle between e and I_1.

$$= e I_1 \cos (\omega + \theta) \quad (9)$$

$$\text{Power} = \text{Torque} (1 - s) \quad (10)$$

As illustration, consider a 25-h. p. motor, 3-phase, 440 volts, 254 volts per circuit, 60 cycles, 6 poles of the following constants:

$Z_m = 2.5 + j\,25$ $\;Z_0 = 0.2 + j\,0.65$ $\;Z_1 = 0.35 + j\,0.65$

Fig. 1 shows the curves as straight induction motor with the secondary short-circuited. Fig. 2 shows the curves

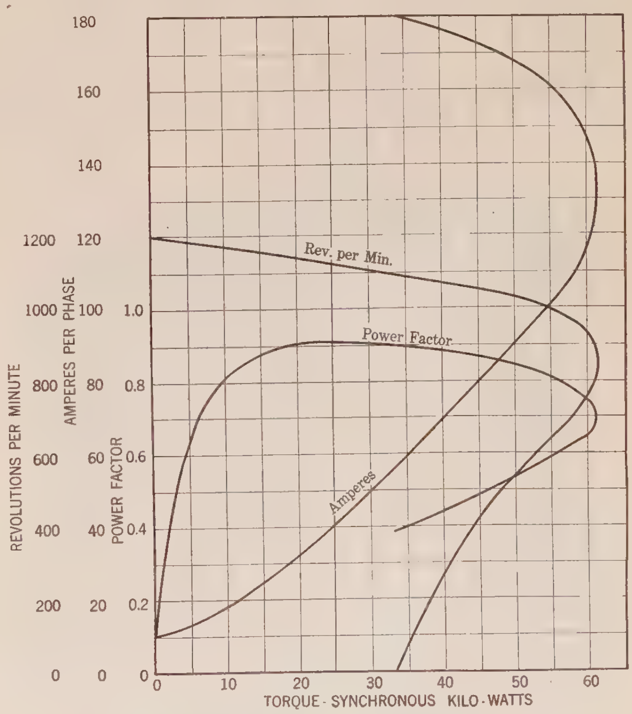

FIG. 2—25-H. P. INDUCTION MOTOR

440 line volts, 254 volts per phase, 3 phase, 60 cycles, 6 poles

with $0.3 \times$ Line Volt impressed on the rotor. With $\theta = 0$, that is no displacement between the stator and rotor circuits, it will be seen that a voltage impressed on the rotor in opposition to the rotor induced volts, reduces the speed, current, torque and power factor. With the brushes shifted $\pi/4$ radians in positive direction, the current is increased, but the torque and power factor are still further reduced. In fact, the rotor de-

velops a small torque at very low speeds only, and mechanical torque must be applied to make it accelerate. With the brushes shifted $\pi/4$ radians in negative direction, the no-load speed is increased, and is above synchronous speed. The torque is greatly increased, as is the power factor, which becomes leading at the higher speeds.

The possibilities of power factor correction, and especially of speed control, are desirable features in machine tool applications and where masses of considerable fly wheel effect have to be accelerated at frequent intervals. That the introduction of an e. m. f. in the secondary of an induction motor has been used only to a very limited extent to obtain these desirable characteristics is undoubtedly due to the fact that commutators have been used as the means of impressing the e. m. f. on the rotor circuits.

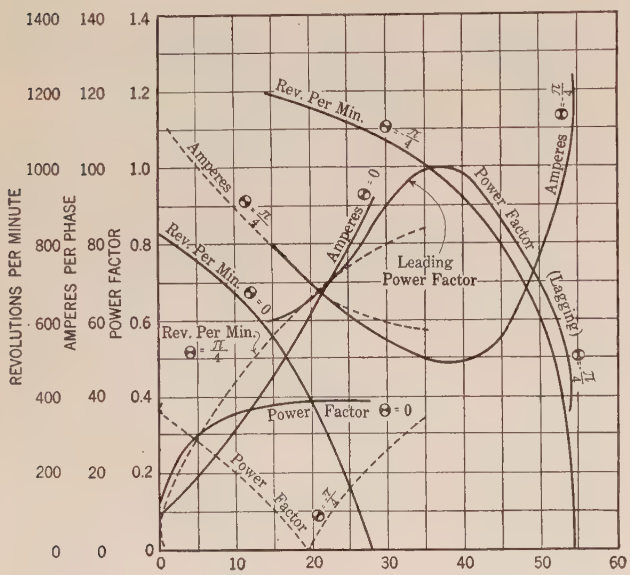

FIG. 3—25-H. P. INDUCTION MOTOR

440 line volts, 254 volts per phase, 3 phase, 60 cycles, 6 poles; 0.3 × line volts impressed on rotor; θ angle of brush shift (electrical); dotted portion of curves indicates negative torque or mechanical power applied to rotor.

As is well known, the current in the rotor coils short-circuited by the brushes must be kept down to a low value to keep the sparking under the brushes from becoming destructive. When expressed in terms of primary, the resistance of the circuit formed by the short-circuited rotor coils is very high, and this limits the current flowing in it to low values. The effect of this current on the speed torque and current curves is therefore small, especially at speeds near synchronism, but it does modify these curves to some extent. To take this effect into account, let the self inductive impedance of the short-circuited coils, expressed in terms of primary, be Z_2, and assume it to be constant, also let the current in this circuit be I_2.

The e. m. f. equations then are

$$(Z_m + Z_0)\, I_0 + Z_m\, \epsilon^{j\theta} I_1 + Z_m I_2 = E \qquad (11)$$

$$s\, Z_m\, \epsilon^{-j\theta} I_0 + (s\, Z_m + Z_1) I_1 + s\, Z_m\, \epsilon^{-j\theta} I_2 = c\, E\, \epsilon^{j\phi} \qquad (12)$$

$$s\, Z_m I_0 + s\, Z_m\, \epsilon^{j\theta} I_1 + (s\, Z_m + Z_2)\, I_2 = 0 \qquad (13)$$

Solving these equations

$$I_0 = \frac{E\,[s\, Z_m\,(Z_1 + Z_2) + Z_1 Z_2] - c\, E\, Z_m Z_2\, \epsilon^{j(\theta+\phi)}}{(Z_m + Z_0)\,[s\, Z_m\,(Z_1 + Z_2) + Z_1 Z_2] - s\, Z_m^2\,(Z_1 + Z_2)} \qquad (14)$$

$$I_1 = \frac{c\, E\, \epsilon^{j\phi}\,[s\, Z_m Z_0 + Z_m Z_2 + Z_0 Z_2] - E\, s\, Z_m Z_2\, \epsilon^{-j\theta}}{(Z_m + Z_0)\,[s\, Z_m\,(Z_1 + Z_2) + Z_1 Z_2] - s\, Z_m^2\,(Z_1 + Z_2)} \qquad (15)$$

$$I_2 = \frac{-\, c\, E\, s\, Z_m Z_0\, \epsilon^{j(\theta+\phi)} - E\, s\, Z_m Z_1}{(Z_m + Z_0)\,[s\, Z_m\,(Z_1 + Z_2) + Z_1 Z_2] - s\, Z_m^2\,(Z_1 + Z_2)} \qquad (16)$$

The magnetizing current $I_{00} = I_0 + I_1\, \epsilon^{j\theta} + I_2$ (17)

The torque and power can then be calculated from formulas (9) and (10).

A LARGE FREQUENCY CONVERTER

There is now being installed a 35,000-kw. frequency converter at the Hell Gate Station of the United Electric Light & Power Company, New York City.

This set is of interest because it is the first large installation of the type of frequency converter. It consists of a 25-cycle synchronous machine direct connected to an induction motor with 60-cycle stator and 25-cycle rotor. The rotor is held at a speed corresponding to 35 cycles, thus giving a slip frequency in the rotor of 25 cycles. The power transfer in operating from 60 to 25 cycles is partly through the shaft to the synchronous machine, and the rest is electrical output from the induction motor rotor. On account of mechanical features of the design it was found more practicable to wind the induction motor rotor for comparatively low voltage and to use a transformer for connecting to the 25-cycle busses. The synchronous machine is wound for the bus voltage.

The advantage of this type of converter is that it forms a voltage tie between the 60- and 25-cycle systems in addition to the usual function of transferring power from one system to the other.

This installation by the General Electric Co. is nearly completed.

The Norwegian Waterfall and Electricity Department has prepared statistics showing the available and utilized horse power in Norwegian waterfalls. A summary of these statistics has now been made public. It appears that the total available water power in Norway amounts to 12,289,835 horse power, of which 1,363,902 horse power have been developed. The waterfalls owned by the State represent a total potential energy of 2,155,470 horse power.

Shaft Currents in Electric Machines

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Member' A. I. E. E.
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Review of the Subject.*—This paper describes the causes of, and remedies for, the existence of "shaft currents" or "bearing currents" which sometimes flow across the rubbing surfaces of the bearings of electric machinery, thereby gradually damaging the shaft and bearings.*

Up to the present time the only cause of shaft currents that has attracted any particular attention has been the use of sectionalized stators, and the published discussions have been chiefly confined to synchronous alternators. Fleischman[1] and others have shown that sectionalizing causes shaft currents for the reason that the extra reluctance of the joints causes an unequal division of the flux between the clockwise and counter-clockwise paths in the yoke, thus giving a resultant flux linking the shaft.

Applying the same method of reasoning used in the case of sectionalizing to the general case of any machine with segmental punchings, the following facts are shown:

1. A principal cause of shaft currents in revolving electric machines is the use of poles and segments in certain ratios.

2. The frequency of the shaft current due to joints in the stator yoke is an odd multiple of the frequency of the stator flux, the frequency of the shaft currents due to rotor joints is an odd multiple of the rotor frequency, and these frequency multiples are determined by the ratios of poles to segments.

3. Machines with 4, 8, 16, 24, 32, etc., poles are especially likely to have shaft currents, and machines with 6, 10, 14, 22, etc., poles are relatively immune.

4. By the proper choice of the number of segments for use with any machine, or by the use of segments with offset dovetails, or both, shaft currents can be effectively eliminated in most cases.

The possibilities of shaft currents being caused by homopolar action as the result of magnetic flux flowing in the shaft, or by other means, are discussed, and it is concluded that such causes are seldom important. A possible useful application for the theory of shaft currents in the design of a high-current transformer is mentioned, and the possibility of obtaining multiple frequencies from a stationary transformer in this way is shown to be dependent upon the presence of magnetic saturation.

A table of combinations of poles and segments that will cause shaft currents is given, and a bibliography of the subject is appended.

1. Reference No. 8.

CONTENTS

Introduction

A common source of trouble in revolving electric machines is the presence of electric currents flowing across the rubbing surfaces of the bearings. These currents make their presence known by blackening the oil, pitting the bearing, and, in extreme cases, scoring the shaft.

Figs. 1 and 2 show photographs of damage done to a shaft and bearings by these currents. Other photographs are given by Adler[2], who states that currents greater than 1¼ amperes per square inch of bearing surface will damage the shaft, but that currents of lesser magnitude will harm the bearings only.

The usual type of shaft current flows in a circuit consisting of the shaft, the bearing pedestals or end shields, and the base. Interruption of this circuit by insulation under the pedestals, as shown in Fig. 3, is the most usual method of avoiding trouble from this source. In machines with end shield bearings, however, it is very inconvenient to insulate, and in no case does the use of insulated bearings afford any pleasure to either the manufacturer or the operator.

This paper has been written in order to present some supposedly novel ideas on the causes of shaft currents and methods of avoiding them. As the published information on this subject is rather scattered, and, being chiefly in German periodicals, is relatively inaccessible to American readers, the previously established principles of the subject are also explained.

Fig. 1—Photograph Showing Effect of Shaft Currents on Shaft of 500-h. p. Induction Motor

First the three possible causes of shaft currents will be described, then the two causes of minor importance

2. Reference No. 6.

To be presented at the Midwinter Convention of the A. I. E. E., Philadelphia, Pa., February 4-8, 1924.

will be briefly discussed, next the major cause will be carefully examined under two headings, then means for avoiding shaft currents will be explained, and finally a possible field of utility for shaft currents will be mentioned.

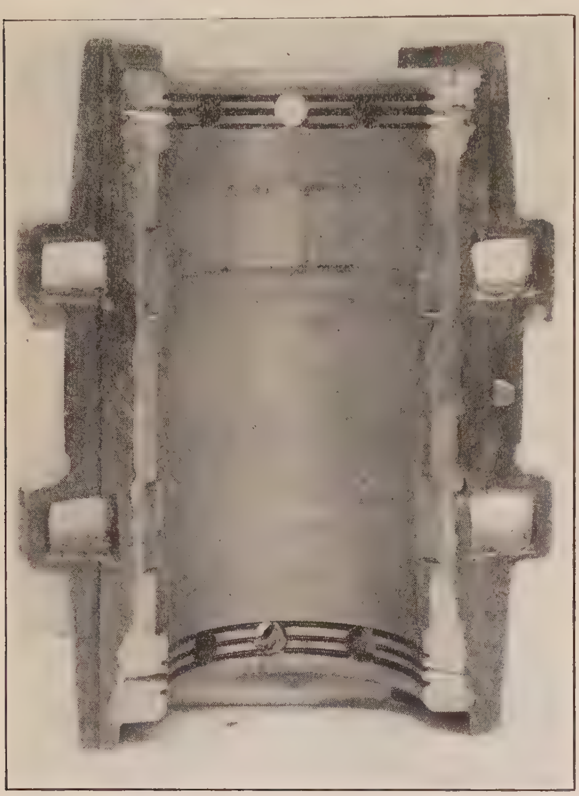

FIG 2—PHOTOGRAPH OF DAMAGED BEARING OF 500-H. P. INDUCTION MOTOR

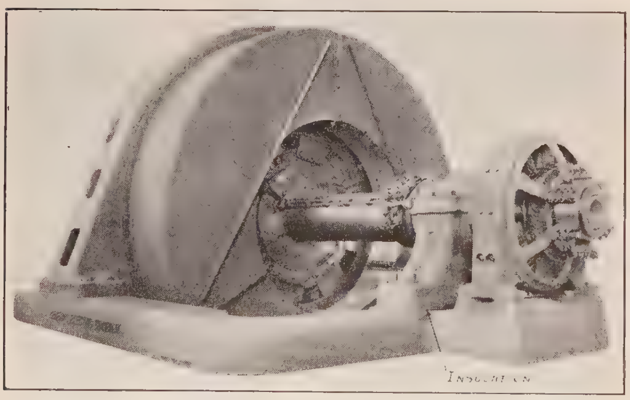

FIG. 3—PHOTOGRAPH OF INSULATED PEDESTAL BEARING

POSSIBLE CAUSES OF SHAFT CURRENTS

All shaft currents are due to the existence of an e. m. f. between shaft and bearing lining. There are three imaginable ways in which such an e. m. f. can be produced:

(a) By a direct or alternating flux flowing in the shaft.

(b) By a difference of potential between shaft and ground due to electrostatic effects, or to grounding of the rotor conductors to the core.

(c) By an alternating flux linking the shaft.

Of these, (c) is by far the most important, and the one which has occupied the greater share of the attention of previous writers. However, in order to leave a clear field for the study of (c) once it has been started, the minor causes (a) and (b) will be first considered.

SHAFT CURRENTS OF TYPE (a), DUE TO SHAFT FLUX

If, for any reason, a magnetic flux flows in the magnetic circuit consisting of shaft, bearings, and base of a machine, a homopolar voltage will be induced in each bearing due to the revolving shaft cutting the radial lines of flux passing from shaft to bearing. The voltages so induced in the two bearings will exactly neutralize, if the flux passing through one bearing is equal to the flux returning from the other bearing to the shaft. Hence such shaft voltages will chiefly cause local currents within the bearings, and insulation of the bearing pedestal from the frame will be of little use,

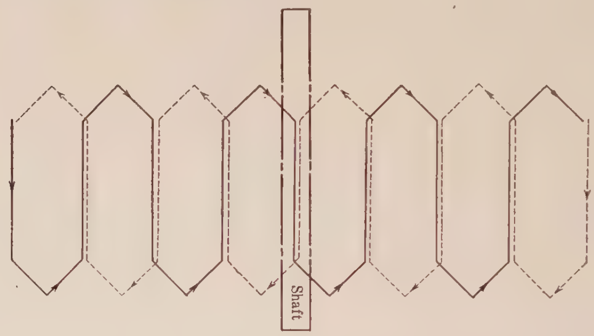

FIG. 4—WAVE WINDING CAUSE OF SHAFT FLUX

except in so far as it increases the magnetic reluctance of the flux path. The most convenient paths for such currents to flow in are from shaft to bearing through an oil ring placed at one end of the bearing and back from bearing to shaft through another oil ring placed at the other end of the bearing.

Whether the shaft flux is direct or alternating, a homopolar voltage will still be induced in the shaft, of the same frequency as the flux. Shaft fluxes will only appear as a result of a current linking the shaft. Only when an unsymmetrical construction of the windings is employed, such as sectionalized end rings for a squirrel cage, or a wave winding with only one bar per slot, will the multipolar machine be subject to this trouble. Homopolar machines, however, are likely to have a good deal of shaft flux.

An inspection of the developed two-circuit wave winding of Fig. 4 shows that the currents in the two circuits encircle the shaft in opposite directions, so that any inequality of these currents will give rise to a shaft flux.

A test was made on a large induction motor with such

a winding on the rotor, to determine if appreciable shaft currents could be produced by shaft flux. One circuit of one phase of the two-circuit rotor wave winding was opened, and the motor was then operated under various starting and running conditions. Although under these conditions all the current of one phase of the rotor linked the shaft, it was found that only a few millivolts were produced between shaft and bearings under the worst conditions. On disassembling the motor after these tests no signs of any shaft currents having been present could be detected.

There are other possible sources of shaft flux, such as uneven air gaps, and others listed by Buchanan[3]. No cases of shaft currents that could be proved due to these causes have come to the authors' attention, however, and it is their belief that the role of shaft fluxes in producing bearing trouble is a minor one. This belief is based on the experiment described above; and on the fact that insulation of the bearing pedestals is a generally accepted and succesful remedy for shaft currents, although such insulation would not materially reduce homopolar shaft currents due to shaft fluxes.

Two methods are available for avoiding trouble from shaft flux, if such trouble is feared. One is the use of non-magnetic bearing pedestals, or the equivalent. The other is the use of a coil linking the shaft through which current is passed in such a direction as to counterbalance the existing m. m. f. available for making shaft flux.

Shaft Currents of Type (b), Due to a Potential Between Shaft and Ground

Electrostatic voltages between shaft and bearings may be set up by the friction of a belt or a pulley, or rubbing friction within the bearings themselves, or by reason of the potential of the rotor winding above ground. Electrical men are familiar with the sparks which may be drawn from a revolving leather belt on a dry day, and with the severe jolt that may be received from touching the frame of an electric motor placed on wooden blocks. Such shocks are evidence of the potential that may be built up by electrostatic effects. It is conceivable that for such reasons as these the rotor of an electric machine may be brought to a potential considerably above ground, and that when the potential reaches a certain value it may discharge through the oil film of the bearing. Constant repetition of such sparks might conceivably in time give the usual pitting effects of shaft currents.

If one part of the rotor winding is accidentally grounded to the rotor core, the whole rotor will be raised above ground potential to the potential of this point of the winding, and so an e. m. f. between shaft and ground will result. If, in addition, the rotor circuit is grounded elsewhere, a short circuit will occur through the bearings. An accident of this kind actually occurred in one instance, with the result that the shaft was badly scarred during the few moments that the power remained on.

No cases are known to the authors where shaft currents of this nature have given trouble except as the secondary results of accidents.

Shaft Currents of Type (c), Due to Alternating Voltages Induced in the Shaft

In every multipolar electric machine, the flux of each pole, after crossing the air gap, divides into two portions, one taking a clockwise and one a counterclockwise path through the yoke. If, for any reason, the clockwise flux, R, is not equal to the counterclockwise flux, L, the effect is the same as if their difference, $R-L$, flowed completely around the yoke. This circulating flux will link the shaft and, if it is alternating, will induce a voltage in the circuit composed of shaft, bearing pedestals, and base, causing a shaft current to flow. This type of shaft current is by far the most important, and the one which has occupied the greater share of the attention of previous writers. It is characterized

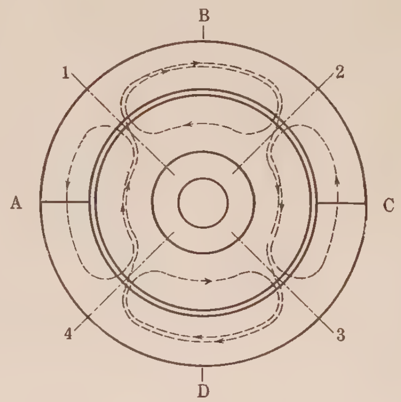

Fig. 5—Production of Shaft Voltages by Yoke Flux

by the approximate equality between the shaft current at standstill, with the secondary open-circuited and full alternating voltage impressed on the primary, and the shaft current in normal operation. Also, this type of shaft current is approximately the same at no-load as at full-load. These characteristics serve to prove that it is not due to the load current, the end turn reactance, or the mechanical arrangement of the end shields, as has been variously suggested.

Consider for example, the classical case of a four-pole alternator with a stator built in two sections as shown in Fig. 5. At A and C the yoke flux passes through regions of much higher reluctance than at B and D. But pole 1 need not send its flux through A. On the contrary, it will send the major part of its flux through B to pole 2, allowing pole 3 to similarly send the larger part of its flux through D to pole 4. Thus the final distribution of flux gives a component linking the shaft, as shown by the sinuous curve of Fig. 5. As 1 will be a north pole at one instant and a south pole one half-cycle later, the flux linking the shaft will alternate at

3. Reference No 2.

line frequency and will cause a shaft current of the same frequency.

This subject of shaft voltages caused by the use of sectionalized stators has been very fully discussed by previous writers, and reference to the articles listed in the bibliography will provide those interested with an over sufficiency of explanatory diagrams and discussions of the matter.

The general law which enables a prediction to be made as to whether or not any given sectionalizing of the stator will cause shaft currents with any given number of poles is:

(1) *Sectionalizing the stator will cause shaft currents if the ratio of twice the number of joints to the number of poles, expressed as a fraction reduced to its lowest terms, has an odd number for its numerator. The frequency of the shaft currents will be equal to this numerator times line frequency. If the numerator is an even number, no shaft currents will appear.*

For example, with 4 joints and 14 poles, the ratio reduces to 4/7, and as 4 is an even number, there are no shaft currents. With 2 joints and 8 poles, the ratio is 1/2, and line frequency shaft currents are set up. The foregoing rule applies only to machines with equally spaced and uniform joints. When the stator is divided into unequal sections special consideration must be given each particular case. In practically every case the joints between sections will vary enough to give some slight dissymmetry and, consequently, a small shaft current even though the numerator of the fraction twice joints over poles is an even number, but such accidental currents should not give serious trouble.

Sectionalizing the d-c. field of a synchronous or a direct-current machine will not cause shaft currents, since the flux linking the shaft will be unidirectional and constant.

Axial holes through the core for ventilation purposes, which are frequently used in high-speed machines, are another source of shaft currents, unless they are so located as to preserve perfect symmetry with respect to the poles. If the pattern of these holes is repeated every pole pitch, no shaft voltages will be produced; otherwise they will be. On the other hand, such axial holes may be so located as to partly neutralize the dissymmetries due to joints in the core, and so may be made to give beneficial effects.

The use of segmental punchings gives effects similar to sectionalizing. The joints in a segmental core are lap instead of butt joints, but they nevertheless have much higher reluctances than corresponding lengths of iron, and so they may cause marked variations between the reluctances of the parallel (clockwise and counterclockwise) paths in the yoke. Tests have indicated that at 8 kilolines per square cm., one lap joint has a reluctance equal to about 25 cm. of yoke, while at densities of 12 and 15 kilolines, respectively, the equivalent lengths of yoke path are roughly 20 and 10 cm.

It is the usual practise to provide each segmental punching with two symmetrically placed dovetails, and therefore to assemble a core with twice as many (lap) joints as there are segments. Thus the use of any given number of segments has the same qualitative effects as the use of twice as many sections. Therefore rule (1) previously stated also applies to the case of segmental construction. It may be restated as follows:

(2.) *The use of symmetrical segmental punchings will cause shaft currents if four times the segments over the poles, expressed as a fraction reduced to its lowest terms, has an odd number for its numerator; and the frequency of the shaft currents will be equal to this numerator times line frequency.*

For example, an eight-pole, six-segment, stator will have three times line-frequency shaft currents, and a 30-pole, 12-segment stator will have no shaft currents. The table of shaft current frequencies given in appendix, Fig. 15, will be found useful in determining what combinations of joints (two times segments) and poles are most favorable.

When the ratio of four times segments to poles is

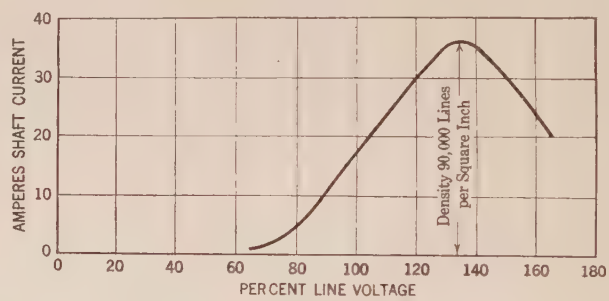

FIG. 6—VARIATION OF SHAFT CURRENT WITH VOLTAGE

unity, all the poles share equally in the production of circulating flux and of shaft voltage. When this ratio is fractional, however, only a corresponding part of the poles contribute to the circulating flux, so that the greater the denominator of the fraction the lower will be the shaft voltage. Also, when the ratio is an odd integer greater than unity, the production of a shaft voltage is dependent on the presence of some degree of saturation in the yoke paths. For, referring to Fig. 7, which illustrates the flux paths in a motor having a ratio equal to 3 ($4 \times 6/8 = 3$), as adjacent joints in the yoke are spaced 120 electrical degrees apart, the algebraic sum of the fluxes passing through 3 consecutive joints is zero, assuming a sinusoidal distribution. If, therefore, the ampere turns at each joint were proportional to the flux, the total ampere turns introduced by the joints into the clockwise flux path would be exactly equal to the ampere turns introduced into the counterclockwise flux path, and no tendency for a circulating flux to appear would exist. Actually, however, the ampere turns across each joint increase at a faster ratio than the flux, and so the two joints per pole in the clockwise flux path give less ampere

turns than the single joint per pole in the counter-clockwise path; a clockwise circulating flux being thus introduced.

In Fig. 6 a graph of a triple-frequency shaft current as a function of voltage is shown, which illustrates the effect of saturation. At very low densities the ampere

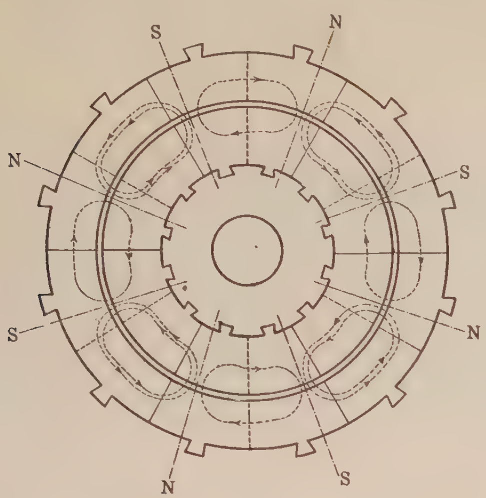

Fig. 7—Production of Shaft Currents in an 8-Pole 6-Segment Motor

turns across the joints are proportional to the flux, and at very high densities the entire yoke becomes so saturated that the reluctance of the entire flux path approaches that of air. In the first case the joint ampere turns in the clockwise and counterclockwise flux paths balance each other and in the second case the joint ampere turns become negligibly small in

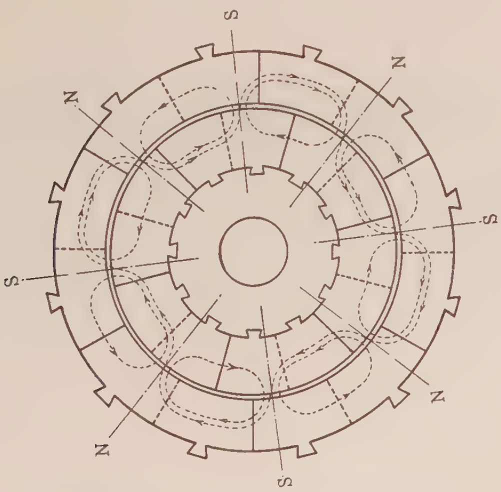

Fig. 8—Production of Shaft Currents in an 8-Pole 6-Segment Motor

comparison with the ampere turns required for the rest of the path; so that in both cases no circulating flux is produced. A very low value at reduced voltage is thus a characteristic of multiple-frequency shaft currents. Line-frequency shaft currents, on the other hand, are more nearly proportional to the voltage at low densities, and decrease less rapidly with saturation, as in these cases there are joints in only one of the flux paths.

When both rotor and stator of an induction motor are made with such a number of segments as to cause shaft currents, the resulting shaft voltage will be equal to the sum of the two shaft voltages that would be caused by the two sets of segments acting separately. The presence of rotor joints has very little influence on the effects of the stator joints, and vice versa. As the slip-frequency shaft voltages due to the rotor segments are small compared with the line-frequency voltages due to the stator segments, the rotor construction is of little importance in considering how to avoid shaft currents.

In order to obtain a clear idea of how a flux linking the shaft is set up in an induction motor with segmental rotor and stator, it is worth while to examine Figs. 7, 8 and 9. These show three positions of the rotor of an

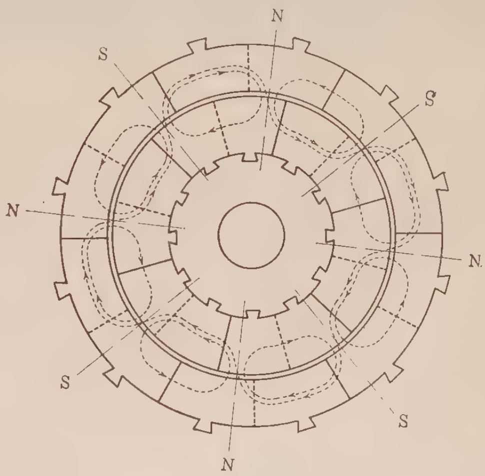

Fig. 9—Production of Shaft Currents in an 8-Pole 6-Segment Motor

eight-pole motor with six segments in both rotor and stator. It is assumed that the slip is negligibly small, and so the center line of a north pole is in the same position on the rotor in every figure.

Consider first the stator alone. In Fig. 7 the flux is in such a position that there is an excess of flux in the clockwise yoke paths, as the reluctance of the eight joints in series in the low-density regions of the core is less than the reluctance of the four joints in series in the regions of maximum core density. In Fig. 8 the flux has moved 1/24 of a revolution and now the counterclockwise flux predominates. In Fig. 9 1/12 of a revolution has been completed and the position is identical with Fig. 7. Thus the stator joints give a flux linking the shaft which completes 12 cycles per revolution, or gives three times line frequency.

Next consider the rotor alone. In all three figures the rotor joints give rise to a predominance of clockwise flux. If it is assumed that the air-gap distribution of

flux is not affected by the unequal division of flux in the stator yoke, it is evident that the effects of the rotor joints are not dependent on the stator joints. At a later moment of the slip-frequency cycle the rotor joints will give a predominance of counterclockwise flux, and after one twelth of a revolution of the flux with respect to the rotor the clockwise flux will again reach a maximum and a cycle of shaft-voltage variation due to the rotor segments will be completed.

Figs. 7, 8, and 9 give a net resultant clockwise flux in the first position, zero flux in the second, and a clockwise flux again in the third position. But one third of a slip cycle later the three positions will give counterclockwise, zero and counterclockwise fluxes. Therefore, the 180-cycle shaft voltage due to the stator segments is simply superposed on the 180 times per cent slip-cycle voltage due to the rotor segments and the magnitudes of each of the two voltages are the same as if they existed independently.

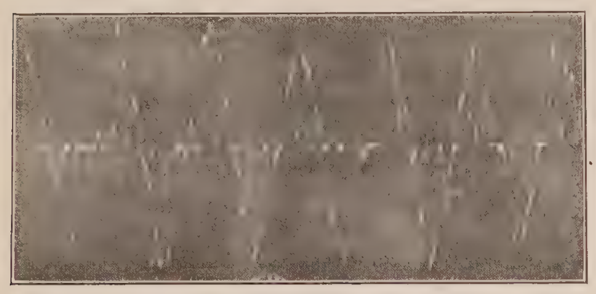

Fig. 10—Oscillogram of Shaft Voltage
Voltage across ends of shaft. Frequency 150 cycles; line frequency 50 cycles.

The shaft voltage shown in Fig. 10 was taken on a 16-pole motor with 12 segments in both rotor and stator. That shown in Fig. 11 was taken on an eight-pole motor with six stator segments and five rotor segments. In neither case is the shaft voltage due to the rotor segments (three times slip frequency in the first case and five times in the second case) large enough to be noticeable.

Fig. 11—Oscillogram of Shaft Current
Current across ends of shaft. Motor running light; frequency 180 cycles; line frequency 60 cycles.

When an induction motor is at standstill, with open-circuit rotor, a shaft current due to the use of the same number of segments in both rotor and stator occurs at n times frequency instead of being composed of two different frequency voltages. But its magnitude then depends upon the rotor position, and it will vary through a complete cycle of values as the rotor is turned through an arc corresponding to one quarter of a segment. As the rotor accelerates the single-frequency shaft voltage breaks up into two components whose frequencies are at first near together and later separate more and more widely until, as full speed is reached, the shaft voltage consists of a large n times line-frequency component and a small n times slip-frequency component. Corresponding to these changes in the shaft voltage the shaft current will change its value in a seemingly erratic manner.

It is a well known fact that the slip of almost any induction motor may be counted by observing the beats of a millivoltmeter placed across the ends of the shaft. The discussion given above clearly shows that the beats of the millivoltmeter are due to a slip-frequency alternating flux encircling the shaft. And the widespread occurrence of this phenomenon shows that even very slight differences in the magnetic paths in the yoke will cause measurable shaft voltages. In many cases the ratio of rotor segments to poles is such as to give shaft voltages 3 or 5 times slip frequency instead of slip frequency itself. For this reason it is well to check the measured slip of an induction motor with a tachometer when the shaft voltage seems to give too high a frequency.

The two oscillograms of shaft currents shown on Figs. 10 and 11 pertain to induction motors with segmental stators having the ratio four times segments over poles equal to 3. In both these cases the oscillograms show the shaft voltages to be at three times line frequency thus verifying the rule (2). The pulsations in the voltage on Fig. 10 are ascribed to tooth-frequency variations in the core flux. It is interesting to note that any third harmonics in the core flux of these machines will give shaft voltages of the same triple frequency that the fundamental flux does, as four times poles over segments for the 3rd harmonic is 1 instead of 3, as for the fundamentals.

In Figs. 12 and 13 are shown oscillograms of shaft voltage taken on two turbine generators with one-piece stator frames. Since in both cases the ratio of four times segments to poles is an even integer, the rules previously laid down do not explain these shaft currents, except on the assumption that they are due to inequalities in the core joints. Evidently the fundamentals of these oscillograms are of line frequency, but the wave forms are extremely irregular. The reasons for these irregularities probably lie in the facts that the actual wave form of the alternator yoke flux is irregular, due to tooth pulsations, harmonics in the field flux, and saturation, and that the passage of this flux through so complicated a magnetic circuit as an annular steel core with irregular air gaps in it gives rise to a still more irregular m. m. f. wave form. If, however, all the joints in the cores had been uniform, no shaft current should have appeared no matter how irregular the flux wave form.

It is the resultant m. m. f. acting around the per-

iphery of the yoke that causes the circulating flux which links the shaft, and this resultant m. m. f., being the difference between two relatively large quantities, has a wave form that is more irregular the smaller its average value. The shaft voltages shown in Figs. 12 and 13 were actually quite small, so that their poor wave forms cannot be taken as an indication that the wave forms of the yoke fluxes were anything like as irregular as they are.

In well designed machines all the important fluxes

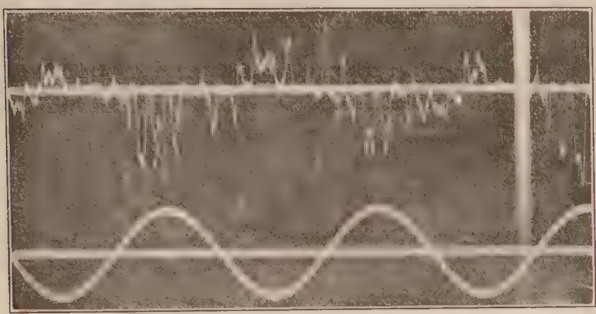

Fig. 12—Oscillogram of Shaft Voltage

Upper curve, voltage shaft to frame. Lower curve, voltage wave no load.

and currents should have closely sinusoidal wave forms, and so the wave forms of any large shaft voltages should be reasonably sinusoidal. Thus the excellent wave form shown in Fig. 11 is not entirely a matter of chance, but an indication of good design. This motor has nearly closed rotor slots and a good ratio of rotor to stator teeth so that only very small tooth-frequency pulsations occur in the yoke fluxes. Also, the wave form of its exciting m. m. f. is very nearly sinusoidal,

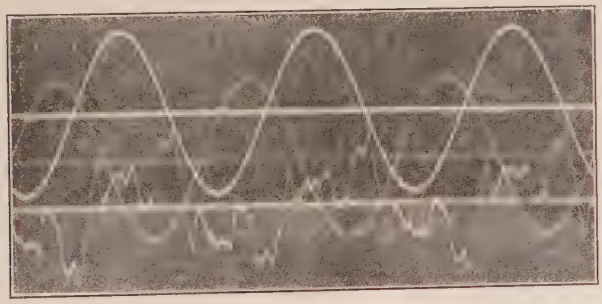

Fig. 13—Oscillogram of Shaft Voltage

Upper curve, voltage, Phase 1-2. Middle curve, voltage, Phase 1-3. Lower curve, voltage, shaft to frame.

its gap permeance is very uniform, and none of the magnetic paths are too highly saturated. Consequently the wave form of its yoke m. m. f. should be very good, as the oscillogram actually indicates.

However, the irregularity of wave form of the three former shaft currents and the regularity of the latter are partly due to the differences in the voltage drops in the shaft circuit. In the turbine generator cases the voltage was taken from shaft to frame, so that the oscillograph current had to return through the other (inaccessible) bearing. In the induction motor cases the voltage was taken across the shaft through metallic brushes, so that the irregular voltage drop across the bearing was avoided. In taking Fig. 10 one brush was on the outside of the revolving shaft, making a rather irregular contact, while in taking Fig. 11 the contacts were made by axially-applied brushes on the two exposed ends of the shaft.

Remedies for Shaft Currents of Type (c)

Of course the first essentials in avoiding shaft currents are to banish the combinations of poles and joints indicated to be objectionable by (1) and (2), or as tabulated in the appended table, and in every case to make the clearances between yoke joints as small and as uniform as possible.

Also, if the shaft and bearings are absolutely smooth and excessive speeds and bearing pressures are excluded, the oil films will act as effective insulators, and so damage to the bearings will be avoided. A large number of motors which are known to have triple-frequency voltages across the shaft of about one volt have been in successful operation for many years, so that small shaft currents are not necessarily dangerous. But any roughness on the shaft or excessive bearing pressure, will cause rubbing, which will allow the currents to flow, and these currents will soon pit the bearings and so aggravate conditions as to in time destroy the bearing surfaces.

The end play of the shaft will usually give intermittent metallic contact from one end of the shaft to the bearing lining, so that the fact that the oil films in the two bearings are electrically in series is of no importance in lessening the currents. The end play explains the fact that frequently the voltage from shaft to ground will be zero on one end of the shaft and yet will be considerable on the other end. The presence of oil rings, which make metallic contact with the top of the shaft, affords a very convenient path for the shaft currents, and for this reason it will often be found that the first signs of bearing currents appear as scratches on the shaft under the oil rings. Thus permanent reliance can not always be placed on the oil film alone as an insulator.

The standard method of avoiding the effects of shaft currents is simply to insulate the bearing pedestals from the bed plate, or the bearing lining from the end shield. Such methods form the simplest way of getting around the difficulty, but they are difficult of adoption on machines with end shield bearings, and they are always a source of trouble and expense.

Several German patents have been taken out on other methods of avoiding these troubles. A common expedient is to place metallic brushes in contact with the ends of the shaft and connect them electrically to the frame, thus short-circuiting the bearings. But the contact drop of the brushes is so great that one-third

to one-half the original current still flows through the bearings.[4] To improve this condition an A. E. G. patent[5] proposes to connect the primary of a transformer across the brushes, the secondary being wound around the core of the machine. By proper arrangements the voltage applied across the brushes may be made to approximately oppose and cancel the line frequency component of the shaft voltage.

Another patent[6] covers the case of a ring-wound coil encircling the stator yoke, this coil being fed with a line-frequency current of such a phase angle as to most nearly cancel the ampere turns set up by the joints. The current in this coil makes a circulating flux in the yoke which opposes the circulating flux set up by the dissymmetry of the magnetic circuit. This scheme affords a method of eliminating the line-frequency component of the shaft voltage but does not avoid the higher frequency currents shown in the oscillograms, Figs. 12 and 13.

A third patent[6] covers the use of an iron collar encircling the shaft inside the bearings, which collar is wound with a ring winding. Application of a suitable line-frequency voltage to this coil sets up an alternating flux whose phase relation to the circulating flux in the yoke is adjusted to give the best cancellation. This scheme also completely cures the fundamental frequency component of the shaft voltage but does not remove the higher frequency components. None of the patented schemes mentioned would benefit in any way the higher frequency shaft currents such as shown in Fig. 10 and Fig. 11 and in fact the application would exaggerate the shaft currents in these cases.

Liwschitz[6] has suggested the cutting of a notch or notches in the yoke in such a way as to add reluctance in the yoke paths that have lower than average reluctance and so bring all the reluctances up to the same level. The simple cutting of such notches in the finished yoke would be very objectionable on account of increased core losses. But a better result can be simply obtained by making butt joints in the punchings to balance the butt joints between sections in those cases where the desirable number of sections is such as to cause bearing currents with the given number of poles. For example, a two-section four-pole motor would now be built with butt joints between sections and lap joints elsewhere, and so would have shaft currents. By making two extra butt joints in the punchings halfway between the section joints, all poles would be made alike and so shaft currents would be eliminated. This assumes that all the four-butt joints could be made very closely alike.

Preferred Method of Avoiding Shaft Currents Due to Segments

The methods so far considered apply equally well to shaft currents due to sectional and segmental stators, but the methods involving the introduction of a bucking e. m. f. are of no use in the case of certain numbers of segments in both rotor and stator. If segments alone are the cause of trouble, as is most commonly the case, the best and altogether most desirable method of avoiding shaft currents is to use offset segments.

For, if the segments are laid out as in Fig. 14 instead of as in Figs. 7, 8 and 9 with the dovetail tags (or notches) placed at the 1/8 and 5/8 points instead of the 1/4 and 3/4 points as is usually the case, the core can be built up with four joints per segment instead of two, and 3/4 of the full iron section at each joint instead of only 1/2. This will be accomplished by laying any single pair of layers of punchings with lap joints in the usual way and then laying the next pair of layers upside down, so that the new lap joints come midway between the first lap joints, as shown in Fig. 14. It is not important that the dovetail tags come exactly at the 1/8 and 5/8 points, but it is essential that each tag come opposite a slot or a tooth, so that slots in the turned over punchings will coincide with those in the other punchings.

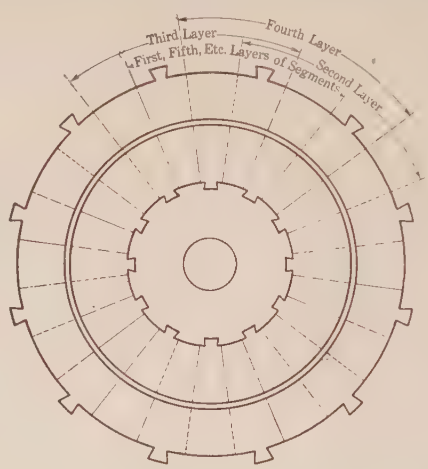

Fig. 14—Core Constructed with Offset Segments

The usefulness of this scheme is somewhat limited by the fact that a blanking die with offset tags will seldom work with more than one number of slots per segment. If the tags are set at the 1/8 and 5/8 points, the number of slots per segment must be a multiple of 4, as 12, 16, 20 and 24. Thus one offset blanking die can be used with 20 and 24 teeth per segment but not with 21 and 22. But the scheme can be used with any combination die. And, the use of this construction will probably reduce the yoke ampere turns and the core losses to a sufficient degree to make it worth considering for these reasons alone, regardless of the shaft current question. Transformer tests have shown that poorly made lap joints may increase the core loss by as much as 20 per cent, while at average densities each lap joint requires as many ampere turns as 6 or 8 inches of the full-section part of the yoke.

A crude alternative to the use of offset segments is to punch ventilating holes in the primary yoke in such a way as to create additional reluctances midway between the joints. These additional reluctances will

4. Reference No 6.
5. Reference No. 5.
6. Reference No. 5.

offset the joint reluctances and so approximate the effect desired. This scheme of course increases the core loss and the yoke ampere turns, and so is not recommended.

Turning Shaft Currents to a Useful Purpose

By constructing both stator and rotor of symmetrical segmental punchings with butt joints and considerable clearances, it would be readily possible to make a large part of the total yoke flux link the shaft. In this way shaft voltages could be produced equal to a fair percentage of the volts per turn in the main winding, and relatively large currents could be drawn from the shaft at low voltages and with fairly good wave form. By

making $2 \times \dfrac{\text{sections}}{\text{poles}} = 1$, 3 or 5, frequencies of 1, 3 or 5

times line frequency could readily be produced. Of course the multiple frequencies would only be due to saturation and so this arrangement would be very inefficient indeed if used as a power-frequency transformer.

Thus a nearly standard induction motor construction could be used to produce large low-voltage single-phase currents at any frequency $(2m - 1)$ times line frequency where m is any integer. Such a machine would have to deliver its current through brushes, and so would have some of the troubles of homopolar machines. Without proceeding to an extreme, an induction motor could be so constructed as to serve the dual purpose of rotating the shaft and also producing low-frequency currents. Of course, any such machine would have to have its bearings well insulated from the frame.

As previously noted, these shaft currents could be as well produced with the rotor stationary, and therefore the motor construction with bearings and air gap is entirely unnecessary, if the sole object is the production of these shaft currents. Such a machine would simply be a static transformer giving a secondary frequency 1, 3 or 5 times the primary frequency. If the frequency ratio is 1, the machine would be exactly equivalent to an ordinary transformer. If the secondary frequency is three or five times the primary frequency, due to proper choice of the segments, the machine is equivalent to a three or five-phase transformer of the usual type, with mesh-connected secondary.

These ideas on the utilization of shaft currents are rather fanciful, and it is not probable that they will be practically developed.

Number of Equally Spaced Joints

Number of Poles	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18	20	22	24	28	30	32	36	40	42	44	48	50	52	56	60	64	66	72
2	-	3	-	5	-	7	-	9	-	11	-	13	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	1	3	-	5	3	7	-	9	5	11	-	13	7	15	-	9	-	11	-	-	15	-	-	-	21	-	-	25	-	-	-	-	33	-
6	-	1	-	5	-	7	-	3	-	11	-	13	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	1	3	1	5	3	7	-	9	5	11	3	13	7	15	-	9	5	11	-	7	15	-	9	-	21	11	-	25	13	-	15	-	33	-
10	-	3	-	1	-	7	-	9	-	11	-	13	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	1	1	-	5	1	7	-	3	5	11	-	13	7	5	-	3	-	11	-	-	5	-	-	-	7	-	-	25	-	-	-	-	11	
14	-	3	-	5	-	1	-	9		11	-	13	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1	3	1	5	3	7	1	9	5	11	3	13	7	15	-	9	5	11	3	7	15	-	9	5	21	11	-	25	13	7	15	-	33	9
18	-	1	-	5	-	7	-	1	-	11	-	13	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	1	3	-	1	3	7	-	9	1	11	-	13	7	3	-	9	-	11	-	-	3	-	-	-	21	-	-	5	-	-	-	-	33	
22	-	3	-	5	-	7	-	9	-	1	-	3	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	1	1	1	5	1	7	-	3	5	11	1	3	7	5	-	3	5	11	-	7	5	-	3	-	7	11	-	25	13	-	5	-	11	-
26	-	3	-	5	-	7	-	9	-	11	-	1	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	1	3	-	5	3	1	-	9	5	11	-	13	1	15	-	9	-	11	-	-	15	-	-	-	3	-	-	25	-	-	-	-	33	-
30	-	1	-	1	-	7	-	3		11	-	13	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	1	3	1	5	3	7	1	9	5	11	3	13	7	15	1	9	5	11	3	7	15	-	9	5	21	11	3	25	13	7	15		33	9
34	-	3	-	5	-	7	-	9		11		13	-	15		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-
36	1	1	-	5	1	7	-	1	5	11	-	3	7	5	-	1	-	11	-	-	5	-	-	-	7	-	-	25	-	-	-	-	11	-
38	-	3	-	5	-	7	-	9	-	1	-	3	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	1	3	1	1	3	7	-	9	1	11	3	3	7	3	-	9	1	11	-	7	3	-	9	-	21	11	-	5	13	-	3	-	33	-
42	-	1	-	5	-	7	-	3	-	1	-	3	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	1	3		5	3	7	-	9	5	1	-	13	7	15		9	-	1		-	15	-	-	-	2	-	-	25	-	-	-	-	3	-
46	-	3	-	5	-	7	-	9	-	11	-	13	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
48	1	1	1	5	1	7	1	3	5	11	1	13	7	5	-	3	5	11	1	7	5	-	3	5	7	11	-	25	13	7	5	-	11	3
50	-	3	-	1	-	7	-	9		11	-	13	-	3	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
52	1	3	-	5	3	7	-	9	5	11	-	1	7	15	-	9	-	11			15		-	-	21		-	25	-	-	-	-	33	
56	1	3	1	5	3	1		9	5	1	3	13	1	15		9	5	11		7	15	-	9	-	3	11		25	13	-	15	-	33	
60	1	1		1	1	7	-	3	1	1	-	13	7	1		3	-	11			1	-	-		7		-	5	-	-	-	-	11	-
64	1	3	1	5	3	7	1	9	5	1	3	13	7	5	1	9	5	11	3	7	15	1	9	5	21	11	3	25	13	7	15	-	33	9
68	1	3	-	5	3	7	-	9	5	11		13	7	15		9		11	-	-	15	-	-	-	21	-	-	25					33	
72	1	1	1	5	1	7	-	1	5	11	1	13	7	5	-	1	5	11	-	7	5		1	-	7	11		25	13		5	-	11	
76	1	3	-	5	3	7	-	9	5	1	-	13	7	15	-	9	-	11	-	-	15	-	-	-	21	-		25	-			-	33	
80	1	3	1	1	3	7	1	9	1	11	3	13	7	3	-	9	1	11	3	7	3	-	9	1	21	11	-	5	13	7	3		33	9
84	1	1	-	5	1	1	-	3	5	11		13	1	5	-	3	-	11	-	-	5	-	-		1	-	-	25	-	-	-		11	-
88	1	3	1	5	3	7	-	9	5	1	3	13	7	15		9	5	1		7	15		9	-	21	1		25	13	-	15		3	-
92	1	3	-	5	3	7	-	9	5	11	-	13	7	15	-	9	-	11	-	-	15			-	21	-	-	25	-	-	-	-	33	
96	1	1	1	5	1	7	1	3	5	11	1	13	7	5	1	3	5	11	1	7	5	-	3	5	7	11	1	25	13	7	5	-	11	3
100	1	3	-	1	3	7	-	9	1	11	-	13	7	3	-	9	-	11	-	-	3	-	-	-	21		-	1	-		-	-	33	-
104	1	3	1	5	3	7	-	9	5	11	3	1	7	15	-	9	5	11	-	7	15	-	9	-	21	11	-	25	1	-	15	-	33	-
108	1	1	-	5	1	7	-	1	5	11	-	13	7	5	-	1	-	11	-	-	5	-	-	-	7	-	-	25	-	-	-	-	11	-
112	1	3	1	5	3	1	1	9	5	11	3	13	1	15	-	9	5	11	3	1	15	-	9	5	3	11	-	25	13	1	15	-	33	9
116	1	3	-	5	3	7	-	9	5	11	-	13	7	15	-	9	-	11	-	-	15	-	-	-	21	-	-	25	-	-	-	-	33	-
120	1	1	1	1	1	7	-	3	1	11	1	13	7	1	-	3	1	11	-	7	1	-	3	-	7	11	-	5	13	-	1	-	11	-
124	1	3	-	5	3	7	-	9	5	11	-	13	7	15	-	9	-	11	-	-	15	-	-	-	21	-	-	25	-	-	-	-	33	-

◇ Denotes combinations, seemingly the worst, where the above given ratio reduces to the odd integer 3. Shaft currents in each of these cases can be completely cured by offset segments.

○ Denotes all other cases given in this table that can be completely cured by offset segments.

COMBINATIONS OF POLES AND SEGMENTS PRODUCING SHAFT CURRENTS.

Fig. 15—Table of Shaft Current Frequencies

In any revolving electric machine, if the ratio of two times joints to poles expressed as a fraction reduced to its lowest terms has an odd number, N, for its numerator, shaft currents of N times line frequency will occur. By line frequency is meant the frequency of the magnetic flux in the jointed element of the machine. This table gives the values of N for various combinations of poles and joints. Combinations with which no shaft currents occur are indicated by dashes.

Conclusions

It is concluded that the most important cause of shaft currents is the presence of some dissymmetry in the magnetic circuits of the rotor or stator core, which causes more flux to flow in one of the two parallel (right and left hand) paths than in the other, and so gives a resultant flux linking the shaft. The most prominent causes of such dissymmetries are sectionalized frames and segmental punchings. All cases where such divisions of the yoke will cause excessive bearing currents can be predicted by means of rules (1) and (2) given above. But the use of any sections or segments at all will give rise to some shaft voltages, due to the impossibility of making all joints exactly alike. These secondary shaft currents should not be harmful except in extremely high-speed machines like turbine alternators.

The most effective methods of remedying bearing currents, other than insulating, are to punch holes in the yoke in the regions of low reluctance, thus raising all parts of the yoke to the same level of reluctance, or to create a separate flux linking the shaft and opposed to the flux produced by dissymmetry or to make use of offset segmental punchings.

It is believed that the use of offset segmental punchings will effectively cure all ordinary cases of bearing currents in small induction motors, d-c. machines, converters and synchronous motors and, as offsetting the dovetails gives better core loss, lower yoke reluctance, and a more solid core construction, with very little expense or trouble (once the new dies are developed), it is recommended that this scheme be adopted whenever practicable.

Bibliography

1. Girault, Paul. On Currents in Dynamo Shafts. (In French) *Bulletin* de la Societe Internationale des Electriciens, Series 3, v. 5, pp. 127-63, Apr. 1, 1915. Same, abstract translation: *Science Abstracts*, Section B, v. 18, pp. 353-54.

Suggests modified theory of bearing currents due to sectionalized stators.

2. Buchanan, W. Currents in Bearings of Electric Generators. *Electrician*, London, v. 75, pp. 266-67, May 28, 1915.

Gives ample list of possible causes of bearing currents.

3. Merrick, E. G. Bearing Currents. *General Electric Review*, v. 17, pp. 936-41. October 1914.

4. Arnold, E. and Lacour. Bearing Currents. (In German) In their *Die Synchronen Wechselstrommaschinen*, 1913, v. 4, pp. 509-11.

Brief discussion of bearing currents due to sectionalized stator.

5. Liwschitz, M. Origin of Bearing Currents and their Prevention. (In German) *Elektrotechnik and Maschinenbau*, v. 30, pp. 704-07, Aug. 25, 1912.

Very sound article on bearing currents giving several practical and effective methods of curing them.

6. Adler, L. Origin of Bearing Currents and their Avoidance. (In German) *Elektrotechnik and Maschinenbau*, v. 28, pp. 157-64, Feb. 20, 1910. Same abstract translation: *Electrician*, London, v. 65, pp. 314-17.

Discusses practical effects of bearing currents and shows photographs of damaged shafts and bearings.

7. Berger, L. Causes of Bearing Currents and their Elimination. (In French) *La Lumiere Electrique*, v. 11, pp. 268-71, Aug. 27, 1910.

Mostly a review of the German investigations.

8. Fleishmann, L. Currents in Bearings and Shafts. (In German) *Elecktrische Kraftbetriebe and Bahnen*, v. 7, pp. 352-53, June 23, 1909.

Originates theory of division of flux between parallel paths in yoke of sectionalized stator.

9. Punga, F. and Hess, W. Bearing Currents. (In German) *Elektrotechnik und Maschinenbau*, v. 25, pp. 615-18, Aug. 11, 1907. Theory and tests. Same, abstract translation: *Science Abstracts*, v. 10, pp. 421-22.

Shows that a sectionalized stator causes bearing currents and gives data on the ampere turns required to force flux across lap and butt joints in the punchings.

Discussion at Spring Convention

LIGHTNING DISTURBANCES ON DISTRIBUTION CIRCUITS[1] (MacLaren);
OPERATING EXPERIENCE WITH CURRENT-LIMITING REACTORS[2] (Pollard);
SHORT-CIRCUIT FORCES ON REACTOR SUPPORTS[3] (Doherty and Kierstead);
STANDARDIZED INSULATOR TESTS[4] (Insulator Subcommittee of Standards Committee);
Pittsburgh, Pa., April 26, 1923.

E. C. Stone: As I understand this lightning situation, the lightning arrester must have large charging capacities. The lightning arrester must choke the dynamic current that may follow from the system. Those two conditions are almost diametrically opposite. However, in very low voltages, by which I mean under four or five thousand the dynamic problem is comparatively simple, and you can hold down the dynamic current following with a low resistance which is not high enough to seriously interfere with your discharge but as you go to the high voltages, the problem of holding back the dynamic current without checking the surge discharge becomes more and more complicated and involves more and more complicated apparatus. At voltages of 150 to 220,000, you have to put so much insulation on to hold the line voltage, that the lightning arrester is not important. I will say that our problem for 234,000 volts is practically solved today by distributing the proper arresters. In that way we can get a high percentage of protection from four thousand volts up to some unknown quantity of 66 or 88 or 110.

I don't see the answer at the present time. Either the equipment is so expensive—I am talking about system protection rather than individual apparatus—if you have big transformers you can afford to pay a little bit for the lightning protection, but in general system protection costs so much that you can't afford to do it from perhaps 119 volts up, until you get to a voltage where your insulation is protection.

Karl B. McEachron: Attention is called in Prof. MacLaren's paper to the desirability of protecting the secondary distribution circuits, especially if those circuits are long and exposed. This point could well receive more consideration than has been given to it in the past. It is well known that the telephone companies have found it necessary to protect their subscribers' stations by the use of arresters, even when the exposed lines were not long. That such protection is necessary has been shown by the burnouts occurring where the circuits were unprotected.

Prof. MacLaren has shown that arresters having high resistance in the ground circuits fail to protect. A simple calculation will show how important this point is, being probably more important with distribution arresters than with the high-voltage equipments.

Assume that a 2300-volt arrester has an effective resistance of 25 ohms which is representative of arresters of this rating. With zero ground resistance, the discharge rate at double rated potential is $4600/25 = 184$ amperes. With a ground resistance of 200 ohms, the discharge rate is only 20 amperes. Thus, the introduction of this ground resistance has reduced the discharge rate to one-sixth of its original value.

Designers of lightning arresters endeavor to get as high a discharge rate as possible, but if one succeeds in reducing the resistance from 25 to 20 ohms or less, his efforts will be of little avail if the ground resistance is not kept low.

This paper agrees with the experience of others in that the best protection is secured where the density of lightning arresters is the greatest. This is, of course, to be expected.

W. B. Kirke: I should like to bring out a few points with regard to Messrs. Doherty and Kierstead's paper that have been particularly interesting to me in a similar study that I have made on magnetic forces in reactors at The New York Edison Co. If we refer particularly to Equation **7**, we will find an expression for the magnetic forces due to the currents in the reactor windings. If we analyze this equation for one complete cycle, we will find that the average force for that period is proportional to the 1.5 term of Equation **7**. If we add up all numerical coefficients of that Equation, $1.5 + 2 + 0.5$ without regard to sign, we will have a Fig. 4 which is proportional to the maximum value of the magnetic force during the first cycle. Equation **7** was derived by squaring Equation **6**. If we had neglected the transient term which occurs in Equation **6** and is expressed by the figure of unity, we would have a force equation which gave over a complete cycle an average force proportional to the figure of 0.5, and

1. A. I. E. E. Journal, 1923, Vol. XLII. March, p. 280.
2. A. I. E. E. Journal, 1923, Vol. XLII, Sept. p. 951.
3. A. I. E. E. Journal, 1923, Vol. XLII, August, p. 832.
4. A. I. E. E. Journal, 1923, Vol. XLII, July, p. 739.

a peak force proportional to the figure of 1 thus representing conditions after the transient has disappeared.

During the first cycle, however, with a totally offset current wave we found that the peak magnetic force was proportional to the figure of 4. This peak force, therefore, varies from a figure of 4 down to the figure of unity during the period of the transient, as shown in the accompanying figure.

In calculating forces in reactors under short-circuit conditions we are, therefore, likely to be greatly in error if the transient currents are not considered. As an illustration, we may take a 300-ampere circuit having a 3 per cent feeder reactor. For a short circuit at the terminals of the reactor, the effective short-circuit current, with sustained bus voltage, would be approximately 10,000 amperes and if this figure were used, it would give us magnetic forces corresponding to the figure of 0.5.

The paper of Messrs. Doherty and Kierstead brings out conclusively that it is not the 10,000 amperes that we should use nor is it the peak value of 14,000 amperes, but it is something like 28,000 amperes or 2.8 times the value of the effective sustained short-circuit current. In other words, we have a maximum force of practically 8 times that which would be derived using the effective sustained short-circuit current. If the decrement is taken into account, the ratio of 8 may be more nearly a ratio of 6.5.

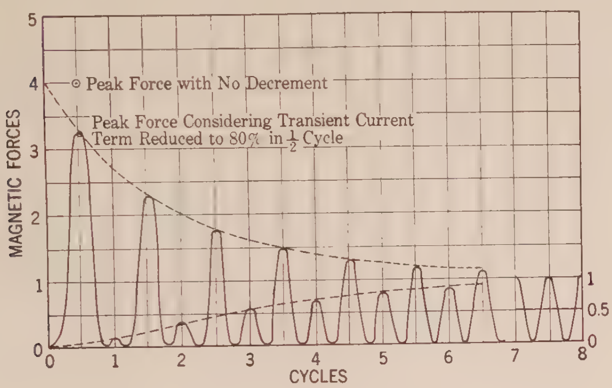

Fig. 1

J. F. Peters: Mr. Pollard's paper brings out the point very forcibly that in going into an entirely new field it is very difficult for the designer to design apparatus that is the final answer. As Mr. Pollard stated regarding these pioneer reactors, the tests at the factory seemed to demonstrate the sufficiency of the design; however, in service, weaknesses developed. The fact that the first designs were not the final answer is clearly brought out by the fact that all reactor builders have modified the construction of their coils since the days when these coils were installed. Service records have demonstrated that the modifications which have taken place since the building of these pioneer reactors have completely overcome all of the weaknesses.

With reference to the third paper by Mr. Doherty and Mr. Kierstead, I feel that the authors should be congratulated for their very interesting and valuable paper. It is a very interesting subject and it is particularly interesting to me because a few years ago I had occasion to investigate a very similar problem—that of forces between bus bars. The same differential equations, of course, apply to the two problems. I had the pleasure of witnessing some short-circuit tests on bus bars. In these tests the bus bars were installed temporarily and the bars forming one lead had considerable separation, with the supports at a considerable distance apart. The short circuit lasted some three or four seconds and during that time we could observe the oscillations of the bars increasing until adjacent bars would collide and destroy the oscillation, after which they would start to build up again.

In investigating bus bar stresses I included one of the electric damping factors, that controlling the decay of the assymmetry at the start of the short, which involves R/L as an exponent. We found that the maximum forces produced by this factor amounted to 2.8 times symmetrical force instead of four times.

I feel that the most interesting and valuable point brought out in the paper is in supplying us with methods of determining the natural period of the coils. We can determine that value and then avoid it in the structure, then design the coil to withstand the maximum electrical forces.

H. O. Stephens: Several years ago there were some points in the design of current-limiting reactors that had not been completely substantiated by actual tests. There was some question as to whether the movement of the conductors due to the forces between them would respond to the instantaneous force resulting from the current at the peak of first half cycle of the displaced current wave. There was also some uncertainty as to the mechanical strength of the cables as they were supported in the reactors.

A large generator, built for short-circuit testing, was provided at Schenectady and a number of reactors were tested to destruction. The result of these tests demonstrated, that for all practical purposes, the peak of the displaced current wave at the first half cycle should be used in calculating the forces between turns. The actual strength of the conductors was also accurately determined. It was then possible to predict with a reasonable degree of accuracy the current that would cause the turns to be displaced in any given design of reactor and apply suitable factors of safety to obtain a reactor of sufficient mechanical strength.

Of particular interest in connection with Mr. Pollard's paper is the fact that after these tests were completed, the strength of a large number of reactors installed was calculated and it was found that some of the reactors of the type shown in Figs. 9, 10 and 11, installed by the Public Service Electric Co. of New Jersey, did not have sufficient mechanical strength and plans had already been started for adding suitable reinforcements before the failures referred to actually occurred.

The point in regard to thermal capacity, brought out in the conclusions to Mr. Pollard's paper, should not be passed over lightly. The reactor should be the last thing to give way in case of a long continued short circuit and a number of operators are specifying that the cross section of the reactor conductor should be at least equal to the cross section of the connected cable. A reactor may easily meet the usual heating guarantees and still have materially smaller cross section but the saving in losses may fully compensate the operator for the increased cost of the reactor with larger conductors.

The need for taking care of the forces between adjacent reactors has been recognized and suitable braces and supports have been provided where the calculated forces indicated their necessity. I do not believe, however, that it has been customary in general to consider the materially increased forces that may result when the natural mechanical frequency is equal to or nearly equal to the electrical frequency. The paper by Mr. Doherty and Mr. Kierstead is a real contribution to the art as it clearly demonstrates certain factors that should be avoided. Fortunately the natural mechanical frequency usually differs materially from the electrical frequency. No failures due to the force between adjacent reactors have come to my attention except one in which, through an error in installation, the braces furnished and intended to take care of this force were omitted. This case however shows that the forces are real and should be recognized in the installation unless adjacent reactors are so far apart that calculations show that they may be neglected.

C. L. Fortescue: The insulator bears to the electric industry a similar relation as the steel rail to the railway industry. It is absolutely necessary to have good insulators in order to be able to operate economically. Now, we have to develop power to

meet the ever increasing demand, this means we have to develop high-voltage transmission lines and to do this we must have good insulators.

One step in order to get a good insulator is to have some standards by which to measure the quality of these insulators. These standards should be uniform for everybody and this Subcommittee of the Standardization Committee, has attempted to formulate rules by which tests should be made to determine the quality of insulators and they have produced a commendable piece of work in this specification.

The problem of the insulator manufacturer is not an easy one. He is dealing with material which is quite tricky and it goes through a large number of rather troublesome manipulations.

I think in order to help the manufacturer of insulators he ought to have sympathetic cooperation on the part of insulator users. He has quite difficult problems and he needs help; he must know under what conditions insulators fail, etc. One way in which the insulator user can help him a great deal is by understanding the manufacturing processes through which an insulator goes. So all insulator users should take an opportunity such as the one that is being presented at this convention to visit an insulator plant and see for themselves the manufacturing processes. The processes in insulator plants are very much alike, and they will not only have an interesting time in seeing these processes, but I think they will learn a lot about insulators.

H. B. Dwight: Messrs. Doherty and Kierstead give an interesting description of the increase, due to motion of the parts, which should be added to the calculated force between reactance coils.

Among the references for calculation of force they give an article by the writer, on "Repulsion and Mutual Inductance of Reactors," published in the *Electrical World* in 1917. This article gave the first approximate formula which was worked out for the repulsion of coils with parallel axes. While its results are very close to the true values, a more accurate and convenient formula is given in the paper by the writer on "Some New Formulas for Reactance Coils," Trans. A. I. E. E., 1919, p. 1681, formula (4). Curves for the force on coils with parallel axes are given in Fig. 3 of the A. I. E. E. paper.

Formulas and curves for the force exerted between coils with the same axis are given in the paper by the writer on "Repulsion and Mutual Inductance of Reactance Coils with the Same Axis" *The Electric Journal*, May, 1918, p. 166.

E. E. Berger: Referring to Mr. MacLaren's paper, it would seem that the problem in most cases of protecting low-tension circuits, such as 115 and 230 volts, was not very serious and that adequate protection could be supplied where needed at small cost. For 2300 and 13,200-volt service, past experience has proven that adequate protection in the form of lightning arresters is available and so the problem is simply a matter of placing arresters at the proper points of a system and in sufficient numbers. However, much valuable work can still be done in reducing the cost of such protection, or possibly increasing slightly the degree of protection.

D. W. Roper's paper, presented before the Institute in November, 1920, which I believe was the beginning of this class of investigation, has proven very valuable in determining what performance should be expected from lightning arresters designed for distribution circuits. I can say that the General Electric Company has been able to check in the laboratory to a large degree the results obtained by Mr. Roper on the Commonwealth Edison System.

My opinion is that more valuable information can still be obtained from operating lines, especially in regard to the magnitude of lightning disturbances. I feel that a very simple apparatus can be developed to measure and record the magnitude of lightning disturbances. From a study of such data taken over several lightning seasons, much light would be thrown on the whole lightning protection problem.

F. H. Kierstead: After Mr. Pollard candidly discusses his experience with current-limiting reactors of different designs he concludes that, while reactors have in the past been subject to failures of various natures, the modern reactor is a reliable piece of apparatus. Another way of putting Mr. Pollard's conclusions is that as a result of such operating experience modern reactors have been made reliable. The defects in the design and operation of early reactors which did not become apparent until the reactors had been given the test of service, have been corrected.

Failures of reactors may result from the following causes: 1—Over-voltages; 2—Insufficient thermal capacity; 3—Mechanical weakness; 4—Foreign conducting materials.

Since reactors are points of reflection, there was some apprehension as to the magnitude of the voltages that might be built up at these points, and in the early days of the design of current-limiting reactors careful consideration was given to the voltage that they might have to withstand. Experience has shown that as a result of this consideration only a very small number of failures can be attributed to over voltage and it is probable that some of these may have been due to foreign material as will be explained later.

It was always recognized that reactors should have liberal thermal capacity and it soon became the practise to construct them with materials not injured by high temperatures and I know of no failures of reactors due to high tempeature that were constructed with heat resisting materials.

While it has always been recognized that the magnetic forces in reactors were large still, as pointed out by Mr. Stephens in his discussion, their exact magnitude and destructiveness was not at first fully appreciated. Now that they are understood we should not expect a duplication of this trouble.

Experience has shown that the danger of failure due to foreign conducting materials falling or being drawn into a reactor by its magnetic field has not been fully appreciated by operators. Usually an examination reveals the cause of such a failure but sometimes the evidence is destroyed by the resulting arc. In one such case a reactor that failed due to no apparent cause was placed out of doors for some time. At a later examination positive evidence of iron rust was found on the conductors at a point where failure had occurred, clearly indicating that the failure had been caused by the presence of an iron body at this point. This is a source of trouble that can be eliminated by proper education of the operating force.

L. F. Woodruff: In 1920 Mr. O. R. Schurig and the writer undertook a study of the stresses in a-c. busbars and busbar supports due to short-circuit electromagnetic forces. A large number of oscillographic tests were made with transient-pressure-recording devices. A mathematical analysis of the motion of the bar was made on the assumption of "equivalent mass" and "equivalent stiffness" for the bar, and we obtained equations identical with those given by Messrs. Doherty and Kierstead. The oscillographic records furnished excellent checks with the theory. The results of our investigation were given in a general engineering laboratory report having a circulation only inside the General Electric Company.

It is obvious that the important principle brought forth is that conditions of electro-mechanical resonance are to be avoided. It is therefore desirable to calculate accurately the natural frequency of mechanical vibration of systems in which the equivalent mass and equivalent stiffness differ materially from the actual total mass and stiffness. The busbar is the most important illustration of such a case.

A busbar is a continuous beam, and if the assumption be made that each span is of the same length, all spans, except possibly those near the ends of the bar, will move in unison, and each span has therefore the end conditions of a beam fixed at both ends. We will set up the differential equation of motion of such a beam.

In Fig. 2 the slope of the neutral axis at any point equal to

$\dfrac{\delta y}{\delta x}$. If the slope is assumed to be small, so that $\left(\dfrac{\delta y}{\delta x}\right)^2$ is negligible in comparison with $\dfrac{\delta y}{\delta x}$, the curvature is approximately equal to $\dfrac{\delta^2 y}{\delta x^2}$ and the bending moment to $E\,I\,\dfrac{\delta^2 y}{\delta x^2}$, where E is the modulus of elasticity of the material and I is the moment of inertia of the cross-section about the intersection of the neutral plane and the plane of the cross-section. The shear is $\dfrac{\delta}{\delta x}$ (moment), or $E\,I\,\dfrac{\delta^3 y}{\delta x^3}$.

The net vertical force acting on the section $A\,B\,C\,D$ is the

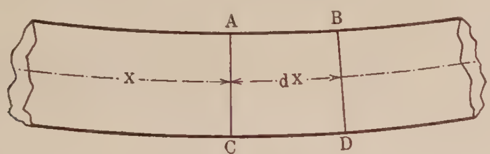

FIG. 2

difference of the shears at $A\,C$ and $B\,D$, and is equal to the rate of change of shear along the X-axis times the distance $d\,x$, or

$E\,I\,\dfrac{\delta^4 y}{\delta x^4}\,d\,x.$

If there is no external force applied, this force must be used in producing vertical acceleration. If m is the mass per unit length of beam, the mass of the section $A\,B\,C\,D$ is $m\,d\,x$, and multiplying this mass by the expression for its acceleration, and equating this to the available force, we have

$$m\,d\,x\;\delta^2 y/\delta t^2 = -\,E\,I\,(\delta^4 y/\delta x^4)\,d\,x,$$

or
$$\delta^2 y/\delta t^2 + (E\,I/m)\,(\delta^4 y/\delta x^4) = 0 \qquad (1)$$

Placing $E\,I/m = p^2$, we have

$$p^2\,\delta^4 y/\delta x^4 + \delta^2 y/\delta t^2 = 0 \qquad (2)$$

On the assumption that the motion of the beam is everywhere sinusoidal with respect to time, we can write

$$y = f\,(x)\,\sin\,(\omega\,t + \phi), \qquad (3)$$

which will satisfy equation (2) if we can find a solution for

$$p^2\,\delta^4 y/\delta x^4 - f\,(x)\;\omega^2 \sin\,(\omega\,t + \phi) = 0 \qquad (4)$$

Differentiating (3) four times with respect to x, and putting $u = f\,(x)$,

$$\delta^4 y/\delta x^4 = (\delta^4 u/\delta x^4)\,\sin\,(\omega\,t + \phi) \qquad (5)$$

Putting $\omega^2/p^2 = f^4$, and combining equations (4) and (5), we have

$$\delta^4 u/\delta x^4 = f^4\,u \qquad (6)$$

By inspection, this equation is satisfied if

$$u = \sin f\,x,$$
$$u = \cos f\,x,$$
$$u = \sinh f\,x,$$
$$u = \cosh f\,x.$$

The general solution is therefore of the form

$$u = M \sin f\,x + N \cos f\,x + P \sinh f\,x + Q \cosh f\,x, \qquad (7)$$

the values of M, N, P and Q being determined by the boundary conditions.

In the case of a beam fixed at both ends, the boundary conditions are that u and $\delta\,u/\delta\,x$ must vanish for $x = 0$ and $x = L$, the length of the beam.

The two conditions for $x = 0$ give

$$N + Q = 0$$
$$M + P = 0$$

The two conditions for $x = L$ give

$$M \sin f\,L + N \cos f\,L + P \sinh f\,L + Q \cosh f\,L = 0$$
$$M \cos f\,L - N \sin f\,L + P \cosh f\,L + Q \sinh f\,L = 0$$

Let $f\,L = \theta$. Then

$$M\,(\sin\,\theta - \sinh\,\theta) + N\,(\cos\,\theta - \cosh\,\theta) = 0 \qquad (8)$$
$$M\,(\cos\,\theta - \cosh\,\theta) - N\,(\sin\,\theta + \sinh\,\theta) = 0 \qquad (9)$$

From (8),

$$M = -\,N\,\frac{\cos\,\theta - \cosh\,\theta}{\sin\,\theta - \sinh\,\theta} \qquad (10)$$

Substituting this in (9) and dividing by N,

$$\frac{(\cos\,\theta - \cosh\,\theta)^2}{\sin\,\theta - \sinh\,\theta} = -\,(\sin\,\theta + \sinh\,\theta),$$

or $\quad \cos^2\theta - 2\cos\,\theta\cosh\,\theta + \cosh^2\theta = -\sin^2\theta + \sinh^2\theta,$

or $\quad \cos\,\theta\cosh\,\theta = 1 \qquad (11)$

Values of θ which will satisfy this equation have been worked out by Strutt (*Theory of Sound*, Vol. 1), and are:

$$\theta = 4.7300408,$$
$$7.8532046,$$
$$10.9956078,$$
$$14.1371655,$$
$$17.2787596, \text{ etc.}$$

The smallest value of θ represents the lowest frequency or fundamental vibration, and the other values the various harmonics. In the fundamental mode of vibration only is the whole span moving in the same direction at any given instant, and resonance of any of the harmonic frequencies with the force frequency is of little importance.

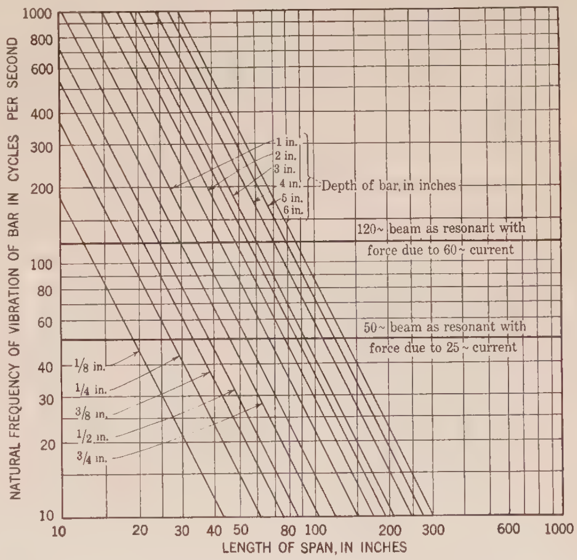

FIG. 3—CURVES SHOWING NATURAL FREQUENCIES OF VIBRATION OF COPPER BARS OF RECTANGULAR CROSS-SECTION, FIXED AT BOTH ENDS

We will now work back and determine the actual frequencies of the various vibrations.

For the fundamental, $\theta = 4.73$.

$$\theta = f\,L. \qquad f = \sqrt{\omega/p}. \qquad p = \sqrt{E\,I/m}.$$

Therefore

$$f = 4.73/L = \sqrt{\omega/p}.$$

$$\omega = \frac{22.37\,p}{L^2} = \frac{22.37}{L^2}\sqrt{\frac{E\,I}{m}}. \qquad (11a)$$

For a beam of rectangular cross-section $I = B\,D^3/12$, where B

is the breadth and D the depth of the beam. The mass per unit length, m, is $B\ D\ x$ density. Putting in these values,

$$\omega = \frac{22.37 \sqrt{\dfrac{E \dfrac{B\ D^3}{12}}{B\ D \times d}}}{L^2}$$

$$= 6.45\ D/L^2\ \sqrt{E/d} \qquad (12)$$

For hard-drawn copper an average value for E is 15,000,000 pounds per square inch, and the density d = 555 lb. per cu. ft. $\div$ (1728 $\times$ 32.2 $\times$ 12) = 0.000832. Putting these values in equation (**12**), we get

$$\omega = 880{,}000\ D/L^2$$

The frequency of the fundamental vibration, $\omega/2\ m$, is

$$140{,}000\ D/L^2 \qquad (13)$$

Curves between length of span and natural frequency, which are straight lines if plotted on logarithmic cross-section paper, are shown in Fig. 3.

The natural frequency of vibration of a copper bar fixed at both ends has been calculated from the partial differential equation as follows. The dimensions D (depth) and L (length) are given in inches. (E = 15,000,000 lb./sq. in.)

Fundamental vibration, 140,000 D/L^2; Second harmonic, 385,000 D/L^2; Third harmonic, 757,000 D/L^2; Fourth harmonic, 1,254,000 D/L^2. For aluminum bars, Fundamental vibration, 197,000 D/L^2.

The natural frequency of vibration of round wires has been calculated, as there is a possiblity of resonance in such apparatus as power-limiting reactors, etc. For round wires of hard-drawn copper, the natural frequency is:

Fundamental vibration, 121,000 D/L^2. For round aluminum wires: Fundamental vibration, 171 000 D/L^2.

M. Mac Laren: Mr. McEachron's illustration of the effect of high ground resistance upon the discharge rate of an arrester I think rather overstates the case for Ohm's Law cannot be applied directly here. As A. L. Atherton has so clearly shown (Paper presented at Midwinter Convention of the A. I. E. E., February 1923) the surge impedance of the circuit will generally be much greater than the resistance of the arrester and its ground connection and has, therefore, a more controlling influence in the problem. At the same time, it is important to obtain low ground resistance and where this cannot be accomplished without considerable expense the arrester density should be increased.

Mr. McEachron's statement that the best protection is secured where the density of arresters is greatest needs qualification, for the data submitted in the paper show that this only applies to the exposed circuits. There are many circuits in the city which have no arrester protection for which no injury from lightning has been recorded. One of the most important matters to determine for the exposed circuits is where the saturation point occurs beyond which it becomes economically undesirable to increase the arrester density.

Mr. Berger refers to the low cost of arrester protection for 115 and 230-volt circuits, and while this is true for an individual case, a large sum would be needed for an operating company to apply such protection at all generally to the system. For these reasons it was suggested in the paper that this type of protection might be included as part of the customer's service equipment.

R. E. Doherty: Mr. Dwight has kindly called attention to additional references to contributions which give methods of calculating the electromagnetic force. These, will be added to the bibliography. Mr. Woodruff has contributed some interesting and valuable equations for calculating the oscillating frequency of bus bars, which are fixed at both ends; and has emphasized the point, referred to on the first page of the paper, that the motion of a bus bar may be represented by equations identical with those for the motion of the reactor. The new equations by Mr. Woodruff make it possible to calculate the natural oscillating frequency, using constants of the material directly, instead of an "equivalent mass" and "equivalent stiffness."

Discussion at Annual Convention

ELECTRICAL LOUD SPEAKERS*

(Nyman), Swampscott, Mass., June 27, 1923

E. W. Kellog: Mr. Nyman has mentioned a series of tests of loud speakers which I think may well be classified into what we might call the engineering tests and the listening tests.

The engineering tests are made with pure sine wave current supplied to the instrument and are to determine, first, what is the sound output per watt input for all frequencies in the useful range; and second, whether the force which acts on the diaphragm bears a linear relation to the current in the winding.

If the sound output per watt input is different for different frequencies, wave form distortion will result, because certain of the overtones present will be exaggerated and others partially suppressed.

If the force-current relation is non linear, the instrument will cause a different type of wave form distortion, producing harmonics which were not in the original.

The test for linear relation between current and force may be carried out by supplying the instrument with a sine wave current strong enough to give the diaphragm a maximum deflection equal to the greatest it will attain in practise. A trained ear can tell whether the resulting tone is practically pure. The current supplied to the instrument should be filtered to insure absence of overtones. Otherwise the instrument will be blamed for faults which are in the source of current.

If the loud speaker produced no distortion of either of the kinds just described, the other tests—listening to speech and various kinds of vocal and instrumental music—would be superfluous. But the loud speakers do not meet the requirements mentioned, especially the requirement of uniform sensitiveness over the whole working range of frequency, and it therefore becomes necessary to judge how seriously the imperfections of the instrument affect the quality of speech and music. This means many listening tests with many listeners, and the balancing of one fault against another, with an integrated appraisal of the various instruments compared. The loud speaker will be sold on the basis of the listening tests but it will be developed and improved through the information gained by the engineering tests.

It is in the tests for relative sensitiveness at various frequencies that the principal difficulties are encountered. These are the tests whose results are shown by curves such as Figures 4, 6, and 10 to 16 of Mr. Nyman's paper.

In view of their importance and the fact that this method of testing loud speakers is being applied in a number of places, I should like to see an interchange of ideas and experiences, and if possible an agreement on test conditions and methods of presenting the results, which will make the results obtained in different laboratories directly comparable.

Without pretending to be especially in a position to lay down standardization rules in regard to tests of this kind, I think that thought on the subject may be promoted and accelerated by my attempting to do so, because it will show what difficulties

*A. I. E. E. Journal, Vol. XLII, 1923, September, p. 921.

or possible sources of error have occurred to me and tentative ways of avoiding them. Others who have had more experience than I have, can perhaps rule out some of these precautions as unnecessary and will probably add others that I have overlooked.

In order to get the proposition into concrete form I am going to suggest a tentative set of test conditions, the general method of testing to be as described in Mr. Nyman's paper, but the following conditions imposed:

(1) The oscillator which provides the current for testing should be provided with a filter to eliminate overtones.

(2) The amplifier between the electrostatic transmitter and the galvanometer should be provided with a tuning, or else a filter so that only the fundamental frequency will affect the galvanometer.

(3) The test room to be at least 15 feet by 15 feet, 10 feet high, with its ceiling and three of its walls heavily damped and the remaining wall hard.

(4) The loud speaker to face the middle of the hard wall, 6 feet above the floor and 6 feet from the wall to the center of the bell of the horn.

(5) The electrostatic transmitter to be located in a hole in the wall, directly in front of the loud speaker, and the floor between the loud speaker and the transmitter to be padded with damping material.

(6) The sound pressures recorded to be divided by 2 to reduce the results to equivalent free space pressure.

(7) Results to be given in dynes per square centimeter sound pressure per volt-ampere supplied to the instrument, accompanied by a statement of the instrument impedance and the maximum peak value of voltage or current which it can handle without distortion.

(8) Departure from standard test conditions to be stated.

Let me now give my reasons for some of the provisions named:

First, the oscillator which provides the current for testing should be provided with a filter to eliminate overtones. Let us take the case of very low tones. You noticed in the curves given in Mr. Nyman's paper that the sensitiveness of practically all of the instruments tested was at least 10 times as great for tones above 500 cycles as for tones below 150 cycles. Suppose we supply the instrument with an electric current of 100 cycles, and then measure the sound output by means of the electrostatic transmitter with amplifiers as indicated in Fig. 8 of the paper. If there are any overtones present in the electric current, those overtones may be reproduced so strongly that they will count very much more in the galvanometer reading than the fundamental, whereas we are only interested in the fundamental. Even if the current supplied to the loud speaker is a pure sine wave, the instrument itself may generate overtones. This will occur if the current-force relation is non linear. The overtones thus generated may be more strongly radiated than the fundamental, and since the purpose of the test is to determine not simply how much noise is produced but how much sound of fundamental frequency is radiated, I have called for a filter or tuning between the electrostatic transmitter and the galvanometer. A vibration galvanometer is an alternative.

Next in regard to the size of the test room: The arrangement I have suggested places the loud speaker fairly close to the electrostatic transmitter, and the other walls farther away. The instrument gives out sound in all directions, and even where we have done the best we can at damping, there will be reflections of a substantial fraction of the sound that strikes the side and back walls. The reflected waves will interfere, producing at certain wave lengths subtractions and at other wave lengths additions to the sound coming directly from the loud speaker. The intensity of the interfering waves will be much reduced by placing the walls that are producing these objectionable reflections well away from the loud speaker. This means using a fairly large room, as well as damping the walls.

Why use a hard wall and locate the electrostatic transmitter in the middle of it, in a hole in the wall? I mentioned that hole in the wall construction because I am not sure that all the electrostatic transmitters that would be used are constructed so that the air pressure cannot equalize on the front and the back of the diaphragm for the longest waves. In most of them, the back is housed in pretty well, perhaps well enough for all practical purposes, so that there will not be pressure equalization. But guarding against any possibility of it, suppose we put the instrument in a hole in the wall that fits it tightly. In some testing arrangements I believe the electrostatic transmitter has been placed some distance from the wall. This means that the sound waves given out strike the wall behind the electrostatic transmitter and come back to produce interference effects. If we place the electrostatic transmitter close to the wall so that it is at a pressure loop and motion node for all wave lengths—then we will get a pressure doubling for all waves, provided the wall is perfectly reflecting.

Next is the question of the distance of the electostatic transmitter from the loud speaker. I mentioned six feet because I think that represents something like the distance that listeners would sit from a loud speaker in a home. I would place the transmitter closer to the loud speaker than six feet, except for the fact that I have some reason to believe there is a pressure variation very close to the horn of a loud speaker which does not represent energy actually radiated. There is a circulation of air which may be described as simply surging back and forth. It is represented by a reaction on the diaphragm not of energy dissipation or energy radiation, but an inertia factor, and may be compared to the magnetic field around an antenna less than a quarter of a wave length from the antenna. You would not think of using such a field as a measure of the energy actually radiated by the antenna. You would go at least a wave length or two away. I should be very glad to hear from any one who can answer the question whether there is such an effect as I have mentioned. I tried to look it up but could not find any literature on the subject, except Rayleigh's formula for the reaction of air on a diaphragm ("Theory of Sound", Vol. II., page 165).

I also suggested that results be given in dynes per square centimeter sound pressure per volt-ampere supplied to the instrument, accompanied by a statement of the instrument impedance and the maximum peak value of voltage or current which it can handle without distortion. While the quality of the loud speaker is pretty much a question of *relative* amplitudes at different frequencies, if we could give the distance and have conditions equivalent to the radiation in free space, without any surrounding walls, and give them in terms of sound pressure per volt-ampere supplied the instrument, we should also have a measure of the sensitiveness of the instrument, which is desirable for purposes of comparison.

The last condition mentioned in my list is that departures from standard test conditions are to be stated—of course that might for some time to come mean stating all conditions, but I think it highly desirable that they be stated in detail.

A. E. Kennelly: The method of testing loud speakers which is presented to us in this interesting paper is a valuable one for getting rapid empirical results. It seems to me that much more definite and scientific information can be obtained through the medium of the motional impedance circle. But in any case, whether we use one method or another, we may consider that the ideal instrument is one which produces a linear relation between the pressure of the air at the transmitter diaphragm and the pressure in free air at a defined point in front of the loud-speaking receiver, that the ratio of the two would measure the efficiency of the system; and that it should be the same all over the acoustic range considered.

It is not reasonable to expect that any such relation can be obtained in the near future, and we can only hope to arrive at it by a succession of approximations.

An ordinary diaphragm has its resonant point or a series of

resonant points. The horn has another; the transmitter has another; the electrical apparatus involved connecting them, may have another or a series of others. So it is only by suitably combining a series of such resonances that we can hope to produce conditions that will produce an equalization over the whole working acoustic range as far as possible. There is so much to be done in this direction, that we cannot expect perfection in the near future.

I think we have all been struck with the enormous advances that have been made in the last few years in the direction of frequency measurements, of repeater circuits, and of Atlantic radio transmissions, that it is evident one year produces at this favored time as much development as might have been expected in a dozen years only a little while ago.

W. H. Martin: Mr. Nyman's four requirements for a good loud speaker can, I think, be adequately expressed by two requirements; first, that the efficiency be constant over the frequency range and, second, that the device used produces no frequencies except those imposed upon it.

In going over this paper, I notice that the so-called "relay type" structure shown in Fig. 5, is described as a new development. Comparing the structure of Fig. 5 with the so-called "balanced armature" type of Fig. 3, it appears to me that the relay type is really a small modification of the balanced armature type. Magnetically the two are practically the same. The relay type appears to have the disadvantage, moreover, of having a more complicated winding system.

In the matter of obtaining a loud speaker which will be distortionless for the frequency and volume range required for reproducing speech and music, it seems to me that the important problem is not so much that of devising a new magnetic structure for converting from electrical power to mechanical motion; it is rather that of properly communicating this mechanical motion to the air. Indications are that there is a larger field for improvements in the vibratory and acoustical parts of the structure than in the electro-mechanical parts.

It would help in reading this paper if the author would state what the units of loudness are in which the curves of the paper are plotted. By loudness we might interpret these units to mean sound power, sound pressure, or, as is often meant by loudness in acoustical work, sensation in the ear. Since the second and third are respectively proportional to the square root and logarithm of the first, it is essential to know what the units are in order to interpret these curves properly.

Referring to the measuring apparatus used, the paper does not indicate that the transmitter and amplifier were calibrated to determine whether or not they are as free from distortion as it is assumed. In regard to the method of testing referred to in the paper, I can say that experience with this method has shown that unless more adequate means are used than are described in this paper for eliminating harmonics from the currents sent through the loud speaker and those given out by the amplifier, the results are open to question, particularly at the lower end of the frequency range.

Paul G. Andres: Two causes contributing materially toward the delinquency of a loud speaker in the matter of faithful reproduction or quality of tone are magnetic and mechanical hysteresis.

Considering the first, the presence of iron in the voice current magnetic circuit causes the diaphragm or armature to respond somewhat differently from what it would were no iron used with the result that foreign harmonics are introduced which tend to distort the output.

Mechanical hysteresis or the mechanical lag of the various movable members contributes further distortion. Spoken words and musical sounds have wave fronts that differ decidedly from pure sine waves. They may be very steep or peaked and consequently distortion may easily be introduced due to the diaphragm, armature or other parts of the vibrating system all of which possess a certain element of inertia or have natural vibration periods of their own not being able to follow the impressed voice currents as readily as they might a pure sine wave, particularly if that be of low frequency. Then too, internal losses in the movable members add to the deviation of the acoustical output from the electrical input.

It would appear as though only an aural comparison of the output with the input can be used in passing final judgement on quality, although a test independent of the opinion of individual observers to determine faithfulness of reproduction or an indication of the distorting factors mentioned would be most desirable if such a one could be evolved.

A. Nynam: I will take up first the discussion by Mr. Kellogg. The first point Mr. Kellogg brought out was a question of engineering tests by the uniformity of volume over the frequency range. Mr. Kellogg made the statement that when the volume is uniform over the whole range of frequencies, it will not be necessary to have the other tests. I can't agree with that statement. The last speaker, I think, brought the point out very clearly. It is a question of the wave form of a combination of different frequencies. An individual frequency might have a wave form that is fairly steep, but a combination of frequencies might have a wave form which is considerably steeper than that, and a test at a single individual frequency will not give an indication of the effect of combined frequencies. That is only one of the things that affect it. Then there are numberless possibilities of combinations of sounds, such as music and singing, say, or different instruments in the orchestra, each one having a combination of different frequencies, and this combination has to be reproduced with exactness.

I fail to see how any test of individual frequency can possibly disclose the operation of the loud speaker in a complicated mixture of frequencies. So from this point of view I believe it will be always essential to have the actual acoustic tests performed on the loud speaker before it can be approved.

The second point brought out by Mr. Kellogg, on the standardization of tests, is very good. This is exactly what ought to come about. As far as the method of tests is concerned, I can't agree with Mr. Kellogg exactly. On the matter of sine waves for the oscillator and a tone filter in the receiving system, he is correct. I believe these steps should be taken, and we have attempted in our work to produce a current as close to a sine wave as possible.

On the other hand, that does not eliminate the test without the tone filter, because the tone filter will indicate the reproduction of the note that you have applied, but that does not exclude the possibility of some other frequencies appearing and distorting the sound; and you couldn't indicate these other frequencies except by making a test without the tone filter.

As far as the arrangement of the room for testing the loud speaker is concerned, Mr. Kellogg's suggestions are good, but I have one exception to offer. Mr. Kellogg suggests placing the loud speaker at a certain distance from the horn in a room especially constructed for the purpose. That is all right, provided the loud speaker were used under those conditions in actual practise. In actual practise, the loud speaker may be placed in a resonant room or in a room highly damped. And in a resonant room, it isn't so much a question of how much sound you get in a certain direction but rather it is, how much energy of sound is produced by the loud speaker.

I believe the problem is really complicated and for final standardization both tests would be required; that is, a directional loudness measurement and an energy of loudness measurement.

Methods for measuring the total energy of sound have not been developed. The only thing I can suggest would be an arrangement similar to the measurement of energy of illumination; in other words, by taking a polar curve around the loud speaker, that will indicate the energy.

With very simple tests that I have conducted, moving the

pick-up in front of the horn, I have observed that on most of the frequencies we have to deal with, the pick-up of sound at any point of the horn, provided the horn is designed properly, is practically the same. It may vary 20 or 30 per cent. Of course, this variation is not appreciable.

Mr. Kellogg is right in saying that the condenser transmitter is not uni-directional. I have taken polar curves of condenser transmitters and have found that especially on the low frequencies the pick-up from the back and the sides may be as high as 50 per cent of the sound from the front. This makes it so much more important to use either the method suggested by Mr. Kellogg or placing the transmitter directly in front of the horn, where the sound from the forward direction is so much larger than any reflected sound can be.

On the point brought up by Mr. Kennelly with regard to motional impedances, as I see it the motional impedance test is an essential feature of an electrical analysis of a loud speaker. Of course, the tests described in this paper are empirical tests applied on a practical scale in the engineering development. They are not pure research work. Motional impedance should be carried out on the loud speakers and on combinations of loud speakers and horns, and I believe that will be one of the best methods for determining the characteristics of different types and the operation of the system as a whole.

Mr. Martin brought up the point of efficiency of loud speaker determining its characteristic—I believe the answer to this is the same as to Mr. Kellogg's statement, that is that the efficiency at individual frequencies will not determine alone the operation of the loud speaker. You should take the efficiency of individual frequencies in combined tones; that is, where a mixture of frequencies is applied, and determine whether the individual frequencies will come out in the values proportional to the input.

Mr. Martin is correct in saying the difference between the relay type and the enclosed armature type is very small. The difference is simply practical. In our manufacturing experience, we have found that the relay type is cheaper to manufacture and is more adaptable to changes necessary for proper operation.

The curves that have been plotted do not refer to any particular unit of sound. All of these curves are only relative curves. We start with a certain voltage and we obtain a certain voltage. It is the comparison of the efficiency of loud speaker transmitter systems that we are after. This transmitter—the condenser transmitter—is the most perfect transmitter that has been found practical, and naturally the loud speaker, for practical purposes, should be adjusted to this most perfect transmitter. But all results are purely relative. The transmitters that we have been using have all been tested and their resonance frequencies are well outside the range of the curves that have been shown.

TRANSATLANTIC RADIO TELEPHONY*

(Arnold and Espenschied), Swampscott, Mass., June 27, 1923.

W. V. Lovell: There are just one or two comments I would like to make on the paper on Transatlantic Radio Telephony, which bring out the need for the development of nomenclature keeping pace with the development of new methods. If we do not keep pace, we are going to have quite a bit of confusion. I don't think that the enterprising people who go ahead and do things ought to hold back until they can get approved language to use.

In this paper we find reference to "radio noise strength" for instance. The whole subject of acoustics is one that must be developed a little bit more for both radio and line telephony. And along with the study of acoustics we want to pay some attention to nomenclature.

In previous papers dealing with long distance radio I have found reference to static level, and that appears to be the same thing as what is meant here by radio noise strength. I don't think that either term is really descriptive. "Static level," like a great many other things that have been called static doesn't remain stationary. At the same time, we could find difficulty with the use of the term "radio noise strength." Apparently the dimensions of the antenna and characteristics of the receiving set are involved as well as the condition in nature which is to be defined or evaluated.

While people are going ahead with the development, the committee on standards should give attention to the terms used as well.

FREQUENCY MEASUREMENTS IN ELECTRICAL COMMUNICATION*

(Horton, Ricker and Marrison), Swampscott, Mass., June 27, 1923.

J. W. Horton: A comment in connection with the frequency measuring work of the Bureau of Standards may be of interest. From time to time they have transmitted standard frequencies from the radio station at the Bureau. On several occasions these have been compared with our standard as follows: The transmitted wave was received in the usual manner, amplified in a radio frequency amplifier and impressed upon a detector circuit which was loosely coupled to a variable frequency oscillator. This oscillator was adjusted, in accordance with our base frequency, to the frequency scheduled to be transmitted by the Bureau. Any difference between the two sources, one in Washington and the other in New York, appeared as a low frequency in the output of the detector. Comparisons made on frequencies of from 500,000 to 1,000,000 cycles per second showed in no case a difference of more than 2500 cycles. On one occasion, at a frequency of 1,000,000 cycles per second, the observed difference was about 25 cycles, being below the audible range.

DISCUSSION ON TRANSMISSION LINE TRANSIENTS*

(Bush), Swampscott, Mass., June 28, 1923

A. Boyajian: I believe one of the puzzling discrepancies, viz., the nature of the wave front, mentioned in this paper is capable of a comparatively simple physical explanation.

Professor Bush states that theory shows the wave front ought to be perpendicular, regardless of the losses; that is, although the wave front will gradually diminish in amplitude due to losses, yet it should always remain perpendicular, but that contrary to theoretical considerations the oscillograms show a sloping and rounding of the wave fronts.

Of the factors that are mentioned as affecting wave front, one is skin effect. Professor Bush says that it is expected to influence the wave front slightly. I believe that skin effect is one of the two dominant factors in influencing wave front, and that for this reason. To get a steep wave front, we need infinite frequency. Now, skin effect increases with frequency, and for infinite frequency skin effect is infinite; that is, the resistance of a conductor for an infinite frequency is infinite. Since the voltages of the harmonics constituting the steep wave front are finite but the impedance of the line to them is practically infinite, therefore the infinite frequency which an absolutely steep wave front represents will be wiped out instantly. It, therefore, is impossible to maintain a rectangular wave front on a line of which the resistance increases with frequency, wiping out the higher harmonics faster then the lower harmonics and rounding out all corners, as the oscillograms show. A very good illustration of this is afforded by water waves. By throwing a pebble into a pool we can create an infinitely complex jagged wave at the very point where the stone falls into the water. What do

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*A. I. E. E. Journal, 1923, Vol. XLII, November, p. 1155.

we expect to notice five or ten feet away? An almost pure sine wave, free from all the steepness and jaggedness of the original wave. Here also the higher harmonics which are responsible for the steepness and jaggedness of the original wave are wiped out very fast, and only the lower harmonics reach any considerable distance, and the wave is then nicely rounded.

The second dominant factor in rounding steep wave fronts is the dielectric loss. According to the theory of the so-called "distortionless circuit," if the resistance and dielectric losses of a transmission line are equal, it transmits waves without distortion even though with a large degree of attenuation. This theory, however, is true only if the losses are the same for all frequencies, otherwise it is not true, and the presence of dielectric loss will further aid distortion. In telephone work the range of frequency necessary for transmission of clear speech is quite narrow, and the total conductor resistance including skin effect may be considered constant in that range of frequencies without serious error. The same assumption may also be made for the dielectric loss, assuming it as leakage loss. For these reasons it is possible to improve purity of speech-transmission on a telephone line by suitably loading it by inductances. However, when we come to the general problem of a steep front on a rectangular wave, which covers the range from direct current in the main body of the wave to practically infinite frequency at the very wave front, the increase of both resistance and dielectric losses with frequency can not be ignored, and the distortionless circuit does not exist. At the higher frequencies the loss in the dielectric is not leakage but true dielectric hysteresis loss which increases with frequency and has a distorting and rounding influence similar to skin effect. If the conductor and dielectric losses are or may be assumed equal to each other for any given frequency (although of a different value at each different frequency) the calculation of the distortion is considerably simplified.

In this connection I also wish to point out an inherent limitation of lumped artificial transmission lines. So far as operating frequency phenomena are concerned, lumped laboratory models are no doubt entirely satisfactory to duplicate the phenomena occurring on uniform lines, but when the problem is that of very high frequencies, steep wave fronts, reflections, etc., is the laboratory model with lumped constants still an exact equivalent of the transmission line with distributed constants? A paper entitled "Abnormal Voltages in Transformers" presented before the Institute a number of years ago by Blume and Boyajian, analyzed in considerable detail the behaviors of lumped coils to very high-frequency voltages and steep waves. It was shown there that coils ordinarily treated as a pure inductance react as a complex network of inductance and capacity at the higher frequencies, and that for rectangular wave fronts they initially react as a condenser not as an inductance. Evidently, the study of very high-frequency waves and transients of transmission lines (which have distributed constants) by laboratory models (which have lumped constants with varying characteristics at increasing frequencies) is inherently limited and difficult.

Both Professor Bush and Professor Dellenbaugh deserve much credit for their painstaking investigations on artificial transmission lines.

J. F. Peters: In Professor Bush's paper I was rather surprised at the disagreement between the calculated surges and those recorded by oscillograms, Figs. 6 and 15. I note that the author states the mathematical solutions are based on the assumption that the line may be completely specified by four fixed constants,—r, l, c, g,—resistance, inductance, capacitance and leakance, per unit length of line. Calculations apparently are based on one value of resistance for all frequency components. Since a rectangular wave is made up of a large number of frequency components and resistance varies widely with frequency, especially high frequency, and all components of a traveling wave are of high frequency, it would be interesting to know what frequency the resistance used corresponded with.

Referring to the appendix, equations 1 do not restrict R to the same value for all frequency components. The solution of 1, therefore, should have the summation sign included $\epsilon^{-\alpha t}$

Equations **1** are linear the same as $I\ R$, representing voltage across a resistance is linear. In the latter case, if we want to determine the $I\ R$ of a distorted current accurately we resolve I into its harmonic components, multiply each component by the value of R that corresponds to that particular frequency and then add up the component voltages. In the same way, if for each frequency component in equation **9**, corresponding to the different values of k, we use the value of alpha corresponding to that frequency, much better agreement will be found between calculated and measured values and in no way will we have violated the restrictions imposed by equations **1**.

Joseph Slepian: I found the discussion on page 7 on wave fronts and over-voltages very valuable although some statements contained therein I think require modification.

It has come to be realized in the last few years that steep wave front surges have in them elements of danger to apparatus not possessed by more slowly increasing voltages and many may imagine that there will be something of a proportionality between the steepness of a wave front and its dangerous potentialities. But Professor Bush points out that the measure of the dangerous quality does not go up indefinitely with the steepness, but that even with an infinitely steep wave front only a finite degree of danger is imposed upon the apparatus.

This feeling that the steeper the wave front the more disastrous the effect of the wave on insulation has been responsible for numerous arguments as to the value of high-resistance lightning arresters. It is argued although such arresters do not have enough discharge capacity to reduce the energy or the voltage in the surge in any marked degree, they do taper off the wave front and thus remove the very dangerous character of the wave. However, even with infinitely steep waves there is a limit to the measure of this dangerous character.

Whether a wave front is steep or not, is of course a relative matter. A wave can never be infinitely steep; there must be some slope to it. To be precise the steepness should be referred to some interval of time.

In all the cases, the time interval that the steepness of the wave should be referred to is the period of some natural oscillation of the apparatus being considered. For example, in the case of a transformer, when a voltage is suddenly impressed and maintained, the voltage distribution within the transformer will differ from the final voltage distribution; and the readjustment of voltage from the initial distribution to the final distribution will ordinarily take place in the form of an internal oscillation.

It is the time of this internal oscillation that is the determining factor as to whether a wave is to be referred to as steep or tapered, when its effect on the transformer is being considered. If the time in which the applied voltage rises to its maximum value is short, compared to the natural period of the internal oscillation, the internal oscillation will have practically its maximum amplitude and the maximum abnormal concentration of voltage on the internal parts of the transformer will be produced. But if the time in which the voltage rises to its maximum value is long compared to the natural period of these oscillations, the amplitude of these oscillations will be very much reduced and the distribution of voltage in the transformer will be more nearly the normal distribution.

The same thing is true as regards the multiplication of voltage on a transmission line, due to reflection at its end. The transmission line also has a natural period, namely: the time for the wave to run down to the end and back again.

Professor Bush states that with short lines a doubling of voltage will be produced just as in long lines at the remote

end—assuming the remote end is open or connected to inductive apparatus. However, since lines are usually energized through inductive apparatus, the natural period of the line is going to come in in determining whether actually a doubling will be obtained or not, due to the transient of the line. That is, to produce a surge on a line requires something of the order of several amperes per kilovolt of surge. Inductive apparatus cannot deliver this current instantly; the surge produced by switching on a generator or transformer must build up relatively gradually, because of the inductance of the apparatus. If it builds up slowly compared to the natural period of the line, a doubling of voltage at the far end over that at the near end will not be produced. There may be an abnormal rise of voltage due to a transient including machine constants, but not one due to the line alone.

In practise, there usually are transformers, inductive apparatus at both ends, at the near end the inductance of the apparatus and at the far end the capacity of the apparatus will both operate to prevent a rise in the voltage at the far end due to switching at the near end, provided the line is not too long. That is, if the natural period of the line is short, compared to the transients involving the machine constants, the line itself will introduce no new element of danger in raising voltage.

The only case that I can see where this doubling on short lines may be obtained is in the case of short-circuits. In the case of a short circuit, there is of course practically no inductance at the point where the short-circuit occurs and so waves may be produced sufficiently steep to double by reflection even on short lines. Fortunately, the polarity of the voltage induced by the short circuit is usually such as to merely reverse the voltage at the reflection point instead of doubling the normal voltage; that is, the voltage changes from plus normal voltage to minus normal voltage. Thus, the amplitude of the surge at reflection is twice normal voltage, but the actual voltage to ground is only normal. However, as regards its effect on the internal distribution of voltage within the reflecting apparatus it is still a surge of twice normal voltage.

Modern transformers are designed so as to be able to stand the sudden application of normal voltage. Hence if a surge does not greatly exceed normal voltage, we do not need to worry about its wave front provided the transformer is properly designed.

V. Bush: In regard to Mr. Boyajian's discussion, there is one point that I wish to emphasize. We have at present an analysis of waves on transmission lines only under the assumption of strictly constant R, L, C and G for the line, and we have no analysis for any other condition. If we could have an analysis which would take into account skin effect, for instance, or many other disturbing factors, it would be very valuable; but apparently such analysis is beyond the range of our present analytical ability. It is hence the purpose of this paper to show what an analysis, based on recognized limited assumptions, corresponds to in the actual case; and how far experiments on smooth artificial lines may be expected to yield reliable information in regard to the transient surges of practise.

In regard to Mr. Peters' comments: We can get a closer approximation to the observed waves if we will correct alpha, that is the attenuation factor, term by term in accordance with the frequency, but that procedure is hardly legitimate from a mathematical standpoint. If we have made a complete analysis on certain premises and then proceed to arbitrarily introduce into our answer certain new assumptions, we may come nearer to an observed result; but we are hardly rigorous in our mathematics.

In regard to Mr. Slepian's comments, there are many cases where we encounter waves that are very nearly perpendicular, and I am pleased that he has enlarged upon this particular point. For example, when an arc breaks, the wave which ensues is initially very nearly a perpendicular wave except for the correction which is due to the passage from the spherical wave to a plane one.

ARTIFICIAL TRANSMISSION LINES WITH DISTRIBUTED CONSTANTS*

(Dellenbaugh), Swampscott, Mass, June 28, 1923.

J. F. Peters: I would like to comment on the paper by Professor Dellenbaugh. The performance of a simple transmission line at normal frequency, where the supply is at one end and the load at the other, can be calculated very accurately and with a small amount of labor. When the load or supply is distributed at several points, or there are a number of branches, the matter becomes considerably more complicated and an artificial line may be desirable; it may offer the easiest method of solution. However, the solution of the performance of the transmission line is not the important problem. The important problem is the solution of the transmission line including the rotating machinery; that is, it should include the reactions of the generators and the synchronous condensers that are generally used on high-voltage transmission.

The reactions in the machines are rather complicated, which would point more toward the solutions by means of artificial set-ups. But the reactions are individual; that is, vary widely for different machines, and particularly vary widely between large and small machines. So that in making a set-up of an artificial line it is necessary to obtain approximately the reactions that will be obtained in the final machine. That being the case, it is necessary to use machines in this miniature or artificial transmission line that have appreciable dimensions.

With reference to abnormal voltage conditions the ones that we are particularly interested in are those in the nature of surges or traveling waves. When an abnormal voltage or surge of this nature strikes an artificial line made up of lumped constants such as those described by Professor Dellenbaugh, although he obtains uniformly distributed capacitance, the conductance is still lumped, and a surge reaching one unit of that artificial line will first penetrate a few turns. Thus the inductance per turn will be only the inductance of that turn. As the surge penetrates further into the coil, it encounters very much higher inductance per turn, because then the inductance is the inductance of those turns plus the mutual inductance of the whole coil. The performance of a surge on a coil of this kind would pass through a wide cycle of constants periodically. It is very interesting to note the absence of these secondary reflections in the oscillograms. However, the secondary reflections in this set-up would have a reflection of approximately one-fiftieth of the length of the whole line, and it is possible that the oscillograph would not record that. It seems to me that with the facilities of artificial lines to date, the results obtained can be used only to corroborate calculations.

O. R. Schurig: An increasing number of the electrical-engineering problems met by transmission-line and operating engineers call for experimental investigations on miniature (or artificial) circuits. The problems are of two kinds:

(1) High-frequency problems, arising in connection with lightning, switching, arcing grounds, etc. The high-frequency problems ordinarily involve measurements at only a few points of a system, the currents frequently are relatively small (*i. e.* far below normal-load values), and the phenomena are of a transient character calling for a sensitive, high-frequency oscillograph. Uniformly distributed line constants are essential.

(2) Normal-frequency problems in large system networks, such as the determination of currents, voltages and their relative phases, both in normal operation and during short circuits. The normal-frequency problems often involve a large number of measuring instruments (frequently thirty, or more, in polyphase

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circuits); the currents are of the order of normal-load magnitudes or greater. Both steady-state and transient-state observations are called for. Indicating instruments exclusively may be used in many cases, while oscillographs are required in others. Lumped-line constants are generally permissible, though sometimes uniformly distributed line constants are preferable.

A question at once arising is whether there is one type of miniature system which will permit the solution of both kinds of problems, that is of both the high-frequency and the normal-frequency problems. Since the "lumpy" type of line is not applicable to the high-frequency problems, the question becomes, more specifically, whether the lines of the type described in the paper are practically applicable to both high-frequency and normal-frequency problems.

The practical success of a miniature system for the solution of normal-frequency network problems calls for the minimum of complications due to measuring instruments, in view of the large number of practically simultaneous observations desired. In the solution of high-frequency problems the practical objection to the use of special measuring instruments (such as those employing vacuum-tube amplifiers) is much diminished because, as a rule, only a few of the special instruments are required.

Hence it is of importance to know how large the rating of the miniature equipment must be made in order that standard instruments may be employed without serious error, for both steady-state and transient-state observations at normal frequencies. It is conceivable that an increased current rating of the miniature circuit would also permit simplifying the measurements of high-frequency transients. It is the object of the following discussion to establish the minimum current rating of the miniature system which will permit the use of standard measuring instruments for normal-frequency problems.

As the author properly points out, the errors due to instruments are of two kinds:

(1) That due to the impedance introduced by series-connected instrument elements, such as ammeter or wattmeter current coils;

(2) The error due to the current abstracted from the circuit by shunt-connected instrument elements, such as voltmeter or wattmeter potential circuits.

The error due to series-connected instruments will be seen from figures for typical ammeters and wattmeters. It will not be attempted to give impedance data for the large variety of instruments of different manufacture. The data given in Table I are representative values indicating the order of the magnitudes. It is to be understood that materially larger values of impedance than those given as well as smaller values, are met among the different types of instruments.

If, for example, 10-ampere and 5-ampere current ratings are chosen, typical values of voltage drop at maximum current are those of Table I. If the ammeter and the wattmeter current-element are connected in series, as for power-factor measurements the combined voltage drops, due to the instruments, are seen to be a negligible percentage of the generator voltage in a 100-volt miniature circuit. However, the drops exceed 5 per cent for the 10-ampere rating, and 10 per cent for the 5-ampere rating, when expressed as a percentage of the line drop over a line having a voltage drop of 10 per cent of the generator terminal voltage. The reason for referring the per cent error, due to series-connected measuring instruments, to the *line drop*, rather than to the generator terminal voltage, is that in network problems the division of currents over parallel-connected lines depends largely on the relative impedances of the lines.

The above considerations call for a miniature-line current rating of the order of 10 amperes for a 100-volt circuit, or 5 amperes for a 200-volt circuit, so that the errors due to the series elements of typical portable ammeters and wattmeters may not approach or exceed 10 per cent. Smaller current ratings will lead to larger errors due to the series elements of the instruments for the circuit conditions under discussion, because, roughly speaking, the impedance drops of the series elements at rated currents increase inversely as the current ratings.

TABLE I

Approximate impedance drops at maximum r. m. s. current at 60 cycles per second

	For 5-ampere rating	For 10-ampere rating
Ammeter	0.50 volt	0.25 volt
Wattmeter current coil	0.65 volt	0.30 volt
Ammeter and watt meter element in series combination		
Voltage drop	1.15 volt	0.55 volt
Per cent drop in a 100-volt miniature circuit	1.15 per cent	0.55 per cent
Per cent drop referred to 10 volts	11.5 per cent	5.5 per cent
Oscillograph*		
Voltage drop	0.3 volt	0.3 volt
Per cent drop in a 100-volt miniature circuit	0.3 per cent	0.3 per cent
Per cent drop referred to 10 volts	3 per cent	3 per cent

Note: The data given apply to one of the customary types of commercial oscillographs, for which the vibrators have 1.5 ohm resistance and a current rating of 0.2 ampere; shunts are used for current values in excess of 0.2 ampere.

The second error mentioned was that due to the current abstracted by voltmeter or wattmeter potential coils. The figures for typical voltmeter and wattmeter potential coils are those of Table II. It is seen that the largest errors due to shunt elements are those of the oscillograph, which gives a 4 per cent error for a 5-ampere circuit rating. For a 200-volt system, the percentage values for current abstracted will be the same as those given in Table II, provided the 300-volt elements are employed.

TABLE II

Approximate current at 60 cycles per sec., at 100 volts

Voltmeter (150-volt element)	0.050 amp.	
Wattmeter potential coil (150-volt element)	0.030 amp.	
Wattmeter potential coil and voltmeter in parallel combination (150-volt elements)		
Total current	0.080 amp.	
Per cent current referred to 5 amperes	1.6	per cent
Per cent current referred to 10 amperes	0.8	per cent
Oscillograph* (at full-scale deflection)		
Current	0.2	amp.
Per cent current referred to 5 amperes	4	per cent
Per cent current referred to 10 amperes	2	per cent

*See note applying to Table I

It may, therefore, be concluded that an a-c. miniature circuit-current rating of not less than 5 amperes and preferably 10 amperes is required to limit the errors, due to the customary portable instruments and oscillographs, to values safely below 10 per cent. In regard to instrument errors, the 200-volt circuit rating is preferable to the 100-volt rating. If, therefore, the type of miniature circuit having distributed circuit constants, such as that described in the paper, can be constructed for the increased current ratings mentioned, the number of different types of artificial circuit could be materially reduced.

The current ratings established apply, of course, to the lumpy type of miniature system, as well.

D. C. Jackson: From the standpoint of the practicing engineer, the value of this struggle with artificial transmission lines and other artificial circuits is to aid in discovering the analysis which will enable one to preconceive the reactions that will occur on an actual line, rather than make the design of the line without a full and adequate comprehension of all the factors that will arise.

But there is another important feature, which was referred to in the President's address, that I want to emphasize, and that is the relation of these things to the educational process.

A good many years ago there was that roomfull of line that has been referred to this morning as the Steinmetz artificial line, and at that time Dr. Pender (who was one of my colleagues at the Massachusetts Institute of Technology) and I had some discussions over the best methods of teaching the subject of power transmission from the theoretical aspects, for the purpose of enabling our students to have a correct vision of the problems. We also about that same time fell into some considerable discussions of the problems of skin effect. The consequence was that there was started a series of experimental investigations of skin effect in various conductors which resulted in a number of papers. Perhaps a quarter of the references in the biblography accompanying Mr. Dwight's paper are papers that arose as a consequence of that argument between Pender and myself, which was later also taken up and carried still farther by Dr. Kennelly when he became a colleague of ours.

At the same time Dr. Pender and I struggled with the problem of a transmission line which could be long, preferably as long as a quarter of a wave length with 60 cycles per second. Consequently, a replica of a line about 1000 miles long with conductors of two or three thousand circular mils and spacing for a couple of hundred thousand volts, was made up. It is quite an expensive affair but it does not occupy a roomful of space by any means. It was made up in that characteristic form that was shown in a paper some years back by Dr. Pender, of pancake coils placed in a toroidal arrangement so as to secure substantially distributed resistance and self-inductance without much mutual induction between coils.

That line was made up with large enough conductors so that it would carry sufficient current for enabling us to put oscillographs, ampere-meters and voltmeters in any part of the line we chose to without disturbing its performance and it works admirably for steady state conditions up to several hundred cycles, per second, but the capacity is lumpy and it does not represent distributed effect with transient conditions.

It is on that line that Professor Ricker, for instance, a good many years ago, as shown in a paper of his, found experimentally the difference in admittance for odd and even harmonics which exist between even and odd quarter wave lengths.

Later Dr. Bush took up this aspect of our work. He came to me one day and urged that our students will not be meeting the present situation in the art unless we can deal with transients experimentally in the laboratory on long lines. One of the outcomes is the artificial line equipment described in the papers by Professor's Bush and Dellenbaugh.

What I want to emphasize is this: that while the sort of work described by Dr. Bush and Professor Dellenbaugh in their papers, and referred to by Mr. Dwight in his paper is directly serviceable to the art, the fact is that that work which you find described in the papers of Bush and Dellenbaugh, and the papers that are referred to by Mr. Dwight that came from Kennelly, Laws, Pierce, and so on, was actually planned for educational purposes and was carried out for those purposes; that the philosophy of the thing is to bring the senior students and graduate students in the engineering school into contact with the most advanced philosophy of engineering structures that we have; and, if possible, carry them on into experimental and mathematical work which advances the state of knowledge to some degree as well as soundly founding them for creative work in the art.

That is not what the physicist would call fundamental research, but it is definite and effective engineering research, and when carried on by senior students and graduate students in laboratories that are associated with the under-graduate work, it affects the junior students by causing a tremendous stir of the heart and expansion of the ambition. If this ideal can be more fully adopted by the engineering schools of the United States and even greater sympathy for it be exhibited by the industries of the United States, it will during the next decade change the whole aspect of our engineering practise, because it will give us a more and more effective group of young engineers coming forth into the profession year by year.

The fact that the thing has been fruitful—it has been carried on for a dozen years at the Massachusetts Institute of Technology as a definite philosophy of engineering education and is carried on in other institutions also to a considerable degree;—that it has been fruitful is shown by the fact that in the bibliographies of the papers presented today and in the discussions related to them you will find that a considerable number of the papers referred to have been produced as a consequence of this philosophy. For instance, papers by Lyons, Kennelly, Laws, Pierce, Affel and others come within the category. Professor Bush as a graduate student came in contact with the ideal and he has been very effectively carrying it on since he joined our staff, along with Professor Dellenbaugh, Professor Kennelly and a number of our other colleagues on the staff of the department from which these papers came.

I do not wish to divert attention from the important problems of engineering practise and the philosophy underlying engineering practise in this matter of long distance transmission of power, but it seems to me that it is worth while introducing here this educational aspect of these papers on account of its great interest to us as electrical engineers since, of the various branches of the engineering profession, probably electrical engineering is more soundly based on the fundamental physics and mathematics than any of the other branches.

Harold W. Buck: There are a few unorthodox considerations that I want to speak of in connection with this general question of power transmission particularly in connection with the papers under discussion. These papers are extremely interesting and exhibit wonderful mathematical and engineering skill but why do we have so many papers on this particular subject? It looks like a confession of weakness somewhere.

One of the speakers has referred to the fact that troubles on transmission systems increase as the square of the size of the network. I think that is quite true. Our very high-voltage systems of great length of today are beginning to bring up difficulties and complications which are really very serious. The papers are the result of this situation and are an attempt to analyze the phenomena and to predict what is going to happen under various conditions.

I think a good test of engineering progress is whether simplification is resulting. If we look around and into our power transmission problems at very high voltage at the present time and apply that test, it seems to me that the result is not satisfactory.

The transmission of power from a piston for instance to a rotating wheel through a connecting rod is a very simple proposition but when the connecting rod is lengthened out to such a distance that its inertia and elasticity become factors which cannot be controlled then some other method must be found.

A transmission line is merely a connecting rod and in the very high-voltage lines of great length the inertia and elasticity are becoming difficult factors to handle and the papers under discussion prove it.

Our big transmission systems at very high voltage are not getting more simple but more complex and I think we will have to admit whether we like it or not that many new troubles are developing in connection with them.

Take for instance a 200-mile line at 220,000 volts. We have here a charging current of the order of 50,000 kv-a. This requires for satisfactory control a synchronous condenser installation approximating in size the power house itself. We accept it from force of habit and tradition but it is a grotesque situation from the standpoint of real engineering. The switches are becoming of enormous size and cost and all controlling apparatus is increasing in complexity and cost. Worst of all instability is increasing. Satisfactory adjustments may be made

for a given set of conditions but if a sudden change occurs as must frequently happen things are thrown badly out of balance.

All of these things we accept as a matter of course because we have gradually been led into them but it would be well to consider under all the circumstances whether we are not really approaching the limit of transmission of power by alternating current.

There is a great deal of loose talk in the papers nowadays of transmission of power a thousand miles at a million volts and super-power bus bars running from New York to San Francisco. This is all, of course, absurd and if any such thing were attempted under the present state of the art I do not think there would be mathematicians enough in the country to figure out what had happened after it was all over.

This is all more or less heretical but it seems to me that engineers should pause occasionally in the evolution of engineering and see whether they are really headed in the right direction. After all, reduced to its lowest terms, transmission of power is merely the transfer of electrons from one point to another. If we consider all that is involved in a three-phase 220,000-volt transmission it seems almost obvious that we are carrying out this physical operation in a very clumsy way.

I have no suggestions to offer except to go slow. However, physicists are learning more and more about electrons, their characteristics and methods of controlling them. I cannot help feeling that before this great long distance super-power problem is worked out satisfactorily some radically new method of transferring electrons from one point to another will be worked out.

F. S. Dellenbaugh, Jr.: I would like to add just one thing, that we have since this paper was written built an artificial cable by this same method. The formulas employed and the constants are a little different but I don't think there is any necessity for describing that separately.

I want to offer one word of apology on the systems in measurement Dr. Kennelly said, "What a perfectly horrible lot of units you have!" I admit it. The difficulty lies in the fact that to make it practical, you must deal with transmission lines in the unit you are used to. You don't design 16,000 centimeters of transmission line—that doesn't mean much to you. You deal in miles, unfortunately, but still you do. And so we have miles in length, feet in spacing, and inches in diameter. The fundamental formulas deal with centimeters in C. G. S. or absolute units. So we must convert from the metric or absolute units of our fundamental formulas for the coils to ultimate dimensions, obtaining the line in miles, feet and inches; and as a result I have attempted to put in the duplicate units all the way through.

It is very interesting to note that the work of Mr. Boyajian on the penetration of transients fits in directly with this kind of work, even though he dealt with transformers and we are dealing with transmission lines. It is the same thing, and it fits particularly on the lumpy type of line. In the old type of lumpy line, if we applied a transient or surge, it would partially penetrate the inductance coils. If they were perfect inductances, with no distributed capacity, there would be no penetration and the surge, when it hit the inductance, would immediately be totally reflected, and therefore the lumpy type of line would be absolutely useless for transient investigation. Practically, the coils must have distributed capacity, and so a transient on a lumpy line does penetrate the coils and does give you curves which represent more or less roughly the same curves you get on smooth lines, but filled with a lot of ripples due to partial reflections. The result is that the behavior of the lumpy line under transient condition depends upon the distributed capacity of the coils, which is an entirely haphazard thing and is not taken into account in the design. If you wish to look at it in that way, all this distributed line has done is to design the distributed capacity of the coil so that it is what you want, and leave out the lumped capacities.

Both Mr. Boyajian and Mr. Peters mentioned skin effect, dielectric losses and their relations. Mr. Peters also mentioned that the penetration of the transient, even in the distributed constant lines, as it went through a single coil, had to go through an infinite number of varieties of inductance. That, of course, is perfectly true, and is one of the points that worried us when we built the lines. So our first line was built with 8-mile sections. We built about 1000 miles of it in order that the sections might be small compared to the total length, and that the total length might be enough to record easily on the oscillograph.

We were very much pleased to find that what we might call the "lumped mutual" of the distributed line has no apparent effect on the oscillograms and that they check remarkably well with the theory. Therefore, we might say that the proof of the pudding is in the eating in this case, and that these minor reflections which occur due to the penetration through the coil are of such a small magnitude that they do not show and are not recorded. That is, we don't attempt to say that we have a line which is exactly the same as an actual transmission line, because the only thing that is exactly the same is another transmission line built the same way. Even then the insulators and ground conditions would be different. But we have built a line which behaves very nearly the same way, near enough so that if we get reasonable checks we know that our theory is on the right track.

If we take fundamental physical laws and arrive at results, then take a transmission line which is somewhere near an actual line and test it and arrive at certain experimental results, then if the experimental results and the theoretical results coincide with reasonable accuracy, we can say. "Well, our theory must be pretty good." The final test is to go out and try it on a real line.

We did that last spring and found that our artificial line was very much better than the real line, because it checked the theory much closer. That of course, is a necessary and expected result because the real line is complicated with a lot of factors that can be eliminated entirely in the artificial line.

For the general study of transients and the development of theory in connection with them, we feel the artificial lines are very good, but we admit entirely all of these questions of errors: The effect of dielectric hysteresis; the fact that you still have skin effect but not as much as you have in the actual line; and the fact that there is a certain amount of lumped mutual and a certain value of cut-off due to periodic structure. They must be there, but the evil of their being there is far less than with the lumpy type of artificial line.

Mr. Schurig mentioned the question of errors due to current carrying capacity and was kind enough to state that the distributed lines can be made larger. With the distributed lines made with round wire, there is only one possible coil that will represent a certain combination of circumstances, so that you cannot make those larger; but with the distributed lines having flat wire, you can make them of any size you please because there are an infinite number of coils that will represent any particular set of circumstances, and as a result you can make the flat wire lines to carry any current you please. It is merely a question of size and expense.

The cost of the 2 lines that we have built—one a thousand miles single-phase, the other 450 miles 3-phase—was 60 cents per mile per phase for both. This covers the manufacture of the coils by an outside concern, and included their profit, I think.

For our work, we have found it much more convenient to use vacuum-tubes and meters drawing small power because that is the way our laboratory works. After you once get a vacuum-tube repeater trained and used to you, and not nervous about the particular person running it, it behaves very well. Every person that takes it up has the same troubles over again. It is apparently impossible to eliminate them by instruction. After it once goes, it behaves very well.

For instance, we have made a number of transient investiga-

tions with a 6-volt storage battery for our supply of power. That gets you away from any question of leads through conduits affecting the first surge. We measure the voltage rise on the line at different points, and the current through the line at different points, with 5 or 6 volts impressed on the near end. You can go up, of course, as far as you please, up to the limit of dielectric strength.

With regard to the errors Mr. Schurig mentioned, I would like to point out one thing: The series connection gives practically negligible errors under most conditions, particularly with transient work. The shunt errors are more serious than he pointed out, if you are dealing with transients. That is, his results were calculated for load conditions and more or less for steady work. What would calculate as a very small shunt error under his method might result in a rather large error if you dealt with transients on a line open circuited, for instance. I do not believe you can get transients on an open-circuited line with any kind of volt-meter across it; that is, even a very high resistance will pull it down greatly. We have found it necessary to go to several megohms resistance across the line in order to use the repeater without error due to the shunt resistance.

I would like to say a word on the scale of the system. The scale can be made extremely small, providing you are willing to go into the difficulties of testing with it. It is a question of a balance between the testing technique and the amount of room you want to give up to the line. Our thousand mile single-phase line is mounted in a rather loose framework. We leave plenty of room around and it stands about 4 feet high; in fact, it is very nearly 4 feet on a side—not quite but we will say a 4-foot cube will include 1000 miles of single-phase line. The 3-phase line is very much larger on account of the way we have mounted the coils. They have been mounted so that mutual inductance can be eliminated; that means a lot of waste room. I don't remember the exact dimensions of the boxes, but they are, roughly, 4 feet square and about 5 feet high and take up, I should say, about 25 per cent more room than the single-phase line in cubic feet. Both of these are used for small current and both of them could be designed in considerably smaller space if it was necessary.

A MINIATURE A-C. TRANSMISSION SYSTEM FOR THE PRACTICAL SOLUTION OF NETWORK AND TRANSMISSION SYSTEM PROBLEMS*

(Schurig), Swampscott, Mass., June 28, 1923.

G. M. Armbrust: Mr. Schurig describes a very practical method for the solution of the most important problems in the design and operation of a transmission system.

The tendency of design of transmission systems generally is toward radial distribution or some limited form of network. This sectionalizing has resulted from numerous and extensive operating troubles occurring on a solidly inter-connected network such as the 12,000-volt transmission system of the Commonwealth Edison Company of Chicago, to which I refer. However, the radial scheme of distribution is expensive as reserve line capacity is required for every unit of load. It is therefore desirable to have some means of quickly solving a number of problems to determine the most economical design within the limits of the capacity of apparatus and protective schemes.

These problems are numerous as every group of load units has different geographic relations and electrical constants. The rapid growth of load makes these problems continuous.

This also brings about another condition; the time required to obtain and install cable makes necessary many temporary arrangements which must operate for a considerable time before an ultimate scheme can be realized.

The miniature a-c. scheme provides means for the practical solution of such cases without too great an amount or complication of equipment. The solution of problems mentioned is perhaps of the greatest commercial value, but as Mr. Schurig points out the scheme permits the investigation of many other problems.

In applying the miniature to the cable transmission system mentioned, it is apparent that solutions can be obtained without the use of a great number of units. Most of the problems would be single phase where a larger number of units are available, while in those requiring three-phase solutions it would not be necessary to represent the system in detail; sections could be represented by single units.

In studying the scheme, I had hoped that the miniature system could be reduced to a smaller scale, perhaps comparable with the d-c. calculating table, but limitations of a-c. measuring instruments make this impractical.

I should like to hear Mr. Schurig's opinion on this, regarding the possible minimum scale of the equipment.

V. Bush: It will not be long in my opinion before every large power system will install a calculating table as a part of its engineering equipment. Because of the much greater information available these tables will probably gradually be constructed as a-c. duplications. In addition to the advantages of the a-c. form mentioned by Mr. Schurig, such tables will allow of the investigation of such matters as are involved in power factor, the proper location and size of correcting apparatus, etc.

An a-c. network may be a single-wire or three-wire representation. The former is of course less expensive and may be installed first, and later form part of a three-wire representation. Single-phase short circuits, unbalance, etc. may be studied on the complete artificial system; but care must be used in order to properly represent the inherent tendency of rotating machinery to balance phases. This is a similar matter to that of proper representation of sustained short-circuit conditions. The constants of the piece of apparatus which represents a generating station must be altered to simulate the field reaction.

Either lumped or distributed constants may be used in the representation. Where only a few types of lines are involved, the latter is probably not much more expensive than the former, and it allows also of some small study of transient effects.

The difficulty of measurements on the a-c. system, without disturbing conditions on adding the meter, may be avoided by the use of the vacuum tube repeater. We have found at the Massachusetts Institute of Technology that this does not involve any great difficulty in maintaining calibration. Current or voltage at any point in the network may be readily measured in this manner without drawing appreciable current. Hence the a-c. representation may be made as small in size as desirable.

There is one point in the artificial system that warrants considerable attention. This is the representation of the generating stations where several are simultaneously connected to the network. It is necessary that the relative phase displacements of the voltages supplied to the corresponding points in the artificial network be adjusted upon each change of load to correspond exactly to the phase displacements that will occur automatically under similar conditions in the actual system. Generating stations may be represented by a voltage supplied from a coil adjustable in a circular field, such as in a polyphase regulator; and the phase adjustment may then be made by rotating the coil manually. Similar treatment is necessary for any large synchronous apparatus in the system. It is not necessary that the coil of the regulator have internal constants corresponding to those of the station represented, for the constants can be added externally and the "generated" voltage maintained manually inside of these. The phase adjustment at each artificial station is a matter depending upon governor regulation. When full data on this point are available it is apparently possible to set up correct rules for the adjustment of phase upon change of load.

The transformers may of course be represented by equivalent

*A. I. E. E. Journal, Vol. XLII, 1923, October, p. 1033.

networks, and all constants reduced to those corresponding to one voltage chosen as base.

A considerable amount of study is necessary before all the points in the manipulation of an artificial network of this sort are worked out. Some such means of attack is, however, imperative in order to properly lay out and operate systems of the magnitude at present projected.

O. R. Schurig: The miniature power generating and transmission system described in the paper has its chief application, as already pointed out, in the solution of *system network* problems, such as the determination of (1) normal load distribution in the lines and in generators, (2) system voltage regulation for balanced or unbalanced loads, (3) transient and sustained short-circuit currents at any point of the system for any kind of short circuit, (4) the behavior of relays during short circuits, (5) current-limiting reactor magnitudes and their best location (6) behavior of synchronous generators and motors in complex systems with several generating stations under changing loads, and short circuits, (7) power factor correction, (8) stability of generating and receiving apparatus on long lines, etc.

Dr. Bush suggests, if I understand him correctly, a type of miniature system of even broader application, namely one capable of solving, in addition to the above type of network problems, a variety of problems on high-frequency transients, such as those involving traveling waves, peak voltages due to lightning, arcing grounds, and switching. If fully developed in a practical form, the type of artificial circuit suggested would clearly represent a universal miniature circuit construction. Some of the developments, still incomplete, which the proposed universal type of miniature system would require are the following:

(1) Development of miniature line units: Miniature units of the "smooth" type would be needed to represent each of the sizes of cables as well as units to represent electrically the various types of aerial line construction. A far greater variety of artificial line units than now available would be called for in the representation of an average transmission system. Furthermore, the development of equivalent miniature generator, motor and transformer units—to meet the small scale of the proposed miniature system—would be necessary, as indicated by Dr. Bush.

(2) Measuring instruments and methods: A miniature system should permit measurements of current, voltage and power to be made with considerable facility. Several years of experience with practical miniature network tests have indicated the necessity of having connected in circuit from 20 to 30 measuring instruments, on an average, for substantially simultaneous readings by the observers. That is a considerable number of instruments, covering a large table, when the customary portable type of instrument is used. In the low-current type of "smooth" miniature system proposed by Dr. Bush, special measuring methods such as those involving vacuum-tube amplifiers are needed. Though considerable progress has been made by Dr. Bush and his associates in the development of such measuring methods, the vacuum-tube amplifier scheme in its present state is probably too delicate and complicated for practical measurements when quick results and a large number of measurements are wanted.

One factor of prime importance in power system network investigations is the measurement of *power*. Experience has shown a visual direct-reading power indicator (such as an ordinary portable wattmeter) to be most essential. For the "smooth" type of miniature circuit, we need a new direct-reading wattmeter of much reduced current and voltage consumption.

The above considerations lead to the following summary:

There is a definite field for each of the two types of miniature circuit under discussion:

The network type of miniature system including synchronous machines and lumped transmission line units, as described in the paper, has already established its practical usefulness for the solution of normal-load and short-circuit problems at fundamental frequency; a large bulk of the pressing problems, both of the routine and research type, in transmission networks may be solved in a practical manner; the current rating of the generator and line equipment should be not less than 5 or 10 amperes. Thus, the equipment necessary and the methods of testing are substantially the customary and well-established ones, including power measurements by portable indicating wattmeters. The use of the miniature equipment by central-station and transmission engineers involves no radical departure from full-size system operation. It is not desirable to further broaden the use of the network type of miniature system by substituting "smooth" circuit elements for the "lumpy" type in an attempt to make it applicable also to high-frequency transient problems. The change would introduce new and unsolved problems of design. If "smooth" type of circuit elements having a current rating of an order of magnitude lower than 5 or 10 amperes were used, the convenient direct-reading type of instruments would no longer be applicable for voltage and power measurements. The vacuum-tube type of instrument has, up to the present time, not reached a state of development in which it can be considered practical for quick results when a large number of substantially simultaneous observations are wanted.

The "smooth" type of miniature line, on the other hand, is called for in high-frequency transient investigations. The current rating of the equipment is preferably below 5 amperes, and a good many of the tests may be so conducted as to require but a small number of measuring instruments, which (in accordance with the practise developed by Dr. Bush[1] and Professor Dellenbaugh[1]) are of the vacuum-tube amplifier type. The design of equipment and the manipulation of the tests call for a high degree of specialization—somewhat outside the field of central-station and transmission-line engineering but well within the field of a University laboratory. A number of the large engineering schools now have technical engineering laboratories supported by the industry. Thus, the transmission engineer's problems calling for smooth-line tests in miniature may be assigned to the proper university laboratory for solution, as has already been done in the past. The new contact thus afforded between the industry and the university seems to be beneficial not only to professors and students; but also to the industry as well.

In reply to Mr. Armbrust's question referring to the possible minimum scale of the a-c. miniature-system equipment, I will say that the size depends on the use to which the miniature system is to be put: If to be used for current measurements only, a much smaller equipment will suffice than for a miniature system intended for power and voltage measurements as well. It is assumed, of course, that indicating instruments are to be employed, at least part of the time. For tests involving *power, voltage and current observations* at several points of a system, a 10-ampere continuous rating at 440 volts (20-ampere short-time rating) has been found to be about the minimum for the line units of resistance and reactance. The figures given are those for the miniature system at Schenectady, as described in the paper. A lower current rating will introduce appreciable errors due to the change of circuit conditions brought about by the insertion of the customary portable measuring instruments, as indicated by Mr. Armbrust.

The minimum practical scale of an a-c. equipment for *current observations only* has not been definitely determined, because there has been no call for such an equipment. It is not at all unlikely that the current rating may be reduced to a value of the order of 50 milliamperes, the measurements to be made with thermocouple a-c. ammeters, some types of which have a voltage drop well below the maximum permissible value set by miniature-line requirements. The design of inductance units for the low current values, such as 50 milliamperes, should not

1. See papers, by the respective authors, read at Annual Convention.

offer great difficulties. In this connection, it will be recalled that there are a number of load division and short-circuit problems which call for current measurements, but not for power and voltage measurements. However, it has been felt in the past that the restriction of the equipment to observations of current only, was not desirable in view of the greatly increased use obtained from a device giving power and voltage data in addition to current. It should be pointed out here that the size and cost of the equipment are not to be expected to be proportional to the current rating on account of the increased number of turns required for the inductance units of lower current rating.

Another matter bearing on the size of the miniature equipment is *the number of circuit units required*. At first thought it might appear that the requisite number of miniature units must closely approach the number of network branches of an entire transmission system. As a matter of fact, there are relatively simple circuit transformations, of a mathematical or geometrical sort, that may be applied to complicated networks to reduce the total number of elements in the mesh of circuits. Transformations of the kind that I have in mind have been worked out by Kennelly[2], Fortescue[3], Evans[4] and others. It is often surprising how much labor is saved by the simplest of transformations.

A SIMPLIFIED METHOD OF ANALYZING SHORT-CIRCUIT PROBLEMS*

(Doherty), Swampscott, Mass., June 28, 1923

W. V. Lyon: As an introduction to the study of transients in electric machinery, Mr. Doherty's paper should prove interesting, but I am sure that neither Mr. Doherty nor any other serious student of the subject would be satisfied with this approximate solution. There is no doubt that a more careful analysis which does not neglect the dissipated forces is more difficult, but rather than proving a deterrent this difficulty makes the problem more interesting.

In electric machinery the only voltages that need ordinarily be considered are due to resistance and to variable flux linkages. If the former are negligible in comparison with the latter, the voltage that appears at the terminals of any circuit equals the time rate of change of the total flux linkages. If the circuit is closed on itself, the terminal voltage is zero, and the time rate of change of the flux linkages is zero; that is, the total flux linkages remain constant. If, on the other hand, a constant direct voltage is applied to an idle circuit, the flux linkages increase directly with the time.

The accuracy with which this "theorem of flux linkages" will predict the results obtained in practise depends upon the relative magnitude of the resistance and the self and mutual inductances. In a transformer the principal component of the transient current diminishes at a rate determined by the ratio of the resistance and the difference between the self and mutual inductances. In a certain 1000-kv-a., 60-cycle transformer this ratio is 56. In this transformer the first rush of current on short circuit is 163 per cent of the steady short-circuit current. If the resistance had been neglected, the first rush would have been 200 per cent, as Mr. Doherty states. The error is nearly 25 per cent. There is also another transient component, which is however but 2 or 3 per cent as large as the one just mentioned. This component diminishes at a rate determined by the ratio of the resistance and sum of the self and mutual inductances. This ratio is ordinarily 5 or 10 per cent, and might safely be assumed to be zero.

In a 75-h. p. induction motor we have tested, the ratio of the resistance to the self inductance was about 2.5 for the stator and 4 for the rotor. The two components of the transient current, instead of being constant as would be the case if the resistance were negligible, diminish at a considerable velocity. The one of higher frequency diminishes at a rate of 74 hyperbolic radians per second, and the one of small frequency at a rate of 48 hyperbolic radians per second. In this motor the first rush of current in one phase would be to a maximum value of about 3300 amperes if the resistance were negligible. Actually the first current rush has a maximum value of about 2200 amperes. In this case, neglecting the resistance leads to an error of 50 per cent, whereas if the resistance is taken into account, students have been able to compute the first current rush with an error of less than 10 per cent.

From these examples it would seem that resistance plays a larger part in determining the first current rush than we might be led to believe from a cursory study of the subject.

A. Boyajian: I think Mr. Doherty's paper is a valuable contribution to the electrical literature in that it gives a physical interpretation to the short-circuit transient, a subject which has been dealt with almost exclusively mathematically in the past, starting with differential equations and finding a complete solution that will satisfy them. It is brought out in this paper in an extremely interesting and visual manner that the short-circuit transient of flux and current is produced by the flux which is trapped in the short-circuited coil. The fundamental principle that no flux can enter or leave a short-circuited coil of zero resistance is used masterfully in analyzing the short-circuit transient of a number of electrical apparatuses.

Of course, ordinarily, short-circuited coils have a certain amount of resistance, by virtue of which flux can gradually penetrate into them or leave them, and the transient decays in a short time to a negligible value in accordance with the attenuation constant of the circuit, as is well known. But Mr. Doherty, I think, is to be commended for maintaining the presentation of the principle simply by ignoring the calculation of the rate of decay, inasmuch as the mathematics of these transients are quite old, but the physical interpretation of the phenomenon new to many.

R. E. Doherty: Professor Lynn considers the principle proposed in this paper as, at best, a poor approximation. What the paper presents is the proof of a useful theorem—at least the author has found it to be useful. Like any other theorem, if it is applied where it is not applicable, unreasonable results follow.

If any one is interested in seeing how the theorem may be *applied* for practical results in the case of induction motors, such as Prof. Lynn mentions, I would refer him to the method outlined in a previous A. I. E. E. paper.[1]

Now I am in complete accord with Prof. Lyon as to the desirability of rigorous attack of any problem of this sort; but in practical engineering I have found that I can stick to rigor up to the point where it leads to hopeless complication. Then I have to do something else—because an answer must be obtained.

The value which I feel is in this method of attacking short-circuit problems lies in the fact that it is possible to visualize what is going on, and in a large number of cases, to get actual quantitative calculations in a very simple manner. In those cases in which it is not possible to make quantitative calculations, one at least can obtain accurately the initial condition, that following the instant or the moment of the short-circuit; and if one who is working on such problems has some notion of what the effect of resistance is, he can from that, estimate close enough for practical purposes the rate of decay of the current.

FLOATING NEUTRAL n-PHASE SYSTEMS*

(Doggett), Swampscott, Mass., June 28, 1923

C. W. Bates: At the bottom of page 1031, Prof. Doggett states:

"Resonance in an n-phase circuit may be defined as the condition under which the total admittance is equal to zero." I think that is subject to correction, the correct statement being "Reso-

2. *Elec. World & Eng.* Sept. 16, 1899, p. 413.
3. *Elec. Jour.* Aug. 1919, p. 350.
4. *Elec. Jour.* Aug. 1919, p. 345.

*A. I. E. E. Journal, Vol. XLII, 1923, October, p. 1021.

1. Short-Circuit Current of Induction Motors and Generators, by Doherty & Williamson. Trans. A. I. E. E., Vol. 40, 1921, p. 509.

*A. I. E. E. Journal, Vol. XLII, 1923, October, p. 1029.

nance in an n-phase circuit may be defined as the condition under which the reactive component of the total admittance (or the total susceptance) is equal to zero." It is rather out of the question to eliminate the power component and, besides, that does not affect the question of resonance.

Just before that Prof. Doggett says: "A quicker way to solve problems of this type is to lay off to scale a triangle of the three line voltages," etc. The vector diagram should not be used for direct calculation except in very special cases but it should be used to interpret the complex quantities as they are determined. Having calculated the complex expression for the distance between the true neutral and the geometric neutral and consequently having located the true neutral on the vector diagram, it is a simple problem to determine the various voltages from the true neutral to the various phase terminals, by using the vector diagram as a visual aid to the expression of the proper terms whose algebraic sum will give the voltage desired. For this purpose the diagram does not need to be drawn with particular accuracy and the final results are obtained with no loss of accuracy whatever.

The graphical picture is a splendid thing and I think that this paper would be improved if the illustrative problem, which Prof. Doggett has on page 1031, were drawn out graphically, both to show to the man who is not familiar with all of the details what is going on and to serve as an aid to calculation. I think that Prof. Doggett is to be congratulated on having called attention to this method of locating the floating neutral. This problem is one which occurs very often and there are very few men outside of the teaching staffs of the colleges and a very few recent graduates who can solve this problem (as well as some similar ones) without a great deal of trouble.

V. Karapetoff: Formulas equivalent to Prof. Doggett's final result (5) were deduced and published by me in 1900 in a little book entitled "Ueber Mehrphasige Stromsysteme bei Ungleichmaessiger Belastung" (Enke, Stuttgart), and I have given them to my students every year at Cornell. I am not raising any question of priority, but wish to indicate that a much more general result can be arrived at in a simpler manner than Prof. Doggett's, and that his eq. (5) follows directly from the more general formula.

Let a be the vector of the voltage between the two neutral points. Then the *net* voltage acting upon the load in phase 1 is $E_1 - a$, and the current in phase 1 is equal to $Y_1 (E_1 - a)$. Thus we have

$$\left.\begin{array}{l} I_1 = Y_1 (E_1 - a) \\ I_2 = Y_2 (E_2 - a) \\ \dots\dots\dots\dots \\ \dots\dots\dots\dots \\ I_n = Y_n (E_n - a) \end{array}\right\} \qquad \textbf{(I)}$$

Adding these equations together and remembering that $\Sigma I = 0$, we find

$$\Sigma Y E = a \Sigma Y \dots\dots \textbf{(II)}$$

from which

$$a = (\Sigma Y E) / \Sigma Y \dots\dots \textbf{(III)}$$

Eq. (**III**) is the fundamental equation for any n-phase star-connected polyphase system, with unsymmetrical voltages and with an unbalanced load. Knowing a, the currents are found from eqs. (**I**). Doggett's eq. (**5**) is a special case of expression for a when the generator voltages are symmetrical.

Eqs. (**I**) and (**III**) have been found of inestimable value in many problems, especially in the study of V and T connections, because these connections may be considered as special cases of star-connected windings with unsymmetrical voltages.

L. A. Doggett: I quite agree with Mr. Bates' correction. Professor Karapetoff has in a few brief steps arrived at a very comprehensive expression for the vector voltage between the two neutrals. Its very generality, however, conceals many rather remarkable particular deductions. The particular aspect which is stressed in my paper is that of the effect of phase rotation on the location of the neutral. In reading Professor Karapetoff's 1900 monograph some seven years ago I failed to get any help on this question of phase rotation. It is easy to see that, given this general expression (III above) and Professor Karapetoff on hand to amplify and explain, many practical deductions would follow. He has given us one such in the last paragraph of his discussion.

In closing it appears to me that an old problem which has never satisfactorily been solved in the literature ordinarily available to the electrical engineer, has been resurrected. It is hoped that this paper and the accompanying discussion will make this problem of polyphase unbalanced circuits moderately easy of solution.

THE QUALITY OF INCANDESCENT LAMPS[1]

(Howell and Schroeder) and

THE ART OF SEALING BASE METALS THROUGH GLASS[2]

(Houskeeper), Swampscott, Mass., June 29, 1923

C. F. Scott: About fifteen years ago the tungsten lamp was evolving quite rapidly. Mr. Houskeeper and I were associated in those days in the Westinghouse Lamp factory, trying to help along the progress of the lamp.

A common method of making the tungsten lamp then before the days of the present long wire was the mixing of fine powdered tungsten with carbon and some kind of glue and then squirting it through a diamond die and taking that soft thread catching it on a piece of paper which was moved back and forth, and then cutting the pieces into almost hairpin shaped filaments. These were then packed in boxes and placed in a carbonizing furnace. They went through a cycle of several hours of carbonizing to burn out the mucilage and leave a compact combination of carbon and tungsten particles.

These hairpins were then placed in some neutral gas, a mixture made of hydrogen and nitrogen, and the current was passed through the filaments, which burned out the carbon and sifted together the little tungsten particles forming a little tungsten hairpin, not very rigid, and a half dozen of these hairpins, more or less were assembled together in a lamp, each of these hairpins as an individual, individually measured, and so on.

Mr. Houskeeper devised a method by which that process which usually took several days, passing through many hands, was reduced to a process of five minutes in which the squirted filament passing down through a few feet of tubing was carbonized by high temperature. Then a current passed through the filament and it came forth this continuous so-called wire of tungsten, which might be a thousand feet long with a uniformity which was otherwise, previously impossible. That led to a wire formed lamp, one filament wound continuously as they are wound now. I think Mr. Houskeeper's name would have been widely known in connection with that process which would have been a very important thing if the rate of progress had been less rapid. The wired lamp of the General Electric came at about the same time and was commercially developed at the same time that this was being developed, so that this stage of the tungsten filament lamp was shortlived on account of the progress.

Another important problem in this old incandescent lamp field has been the problem of getting the current from the outside to the inside of the enclosed lamp or bulb. It seems to me that many of the research processes which Houskeeper used in that earlier work have characterized this next development. There is no phenomenally new discovery. He takes the metals, the common metals, not platinum or some other particular thing, but the common metals and any kind of glass apparently, and by a little physical study of the way of combining, and the form, and the strength, and coefficient of expansion, he forms a new combination which is remarkable. The ability to take the

1. A. I. E. E. Journal, 1923, Vol. XLII, August, p. 809.
2. A. I. E. E. Journal, 1923, Vol. XLII, September, p. 954.

things that we are familiar with, and get some new and almost startling outcome is to me as remarkable or possibly more remarkable than discoveries in new fields.

H. Lemp: In 1885 while connected with the Schuyler Electric Light Company of Hartford, Conn. Mr. Merle J. Wightman and myself were engaged in developing what we called the "Series Incandescent Lamp" for arc light circuits. The plan used before the advent of the series incandescent lamp was to use a number of the regular 100-volt lamps in multiple to absorb the current used in connection with arcs, and we then conceived the idea that it would be much better if a lamp could be made with a filament large enough to take the whole ten amperes of a commercial arc light circuit and be connected in series with arc lamps, instead of in groups of lamps in multiple requiring complicated compensating devices.

As all the early incandescent lamps were limited to something like a one-ampere current, to go from one ampere to ten amperes at that time required some research work as to the manner of passing these relatively big currents through the glass sealing, and if one cares to look at past records one will find an early patent to Mr. Wightman and myself for the use of a platinum ribbon in place of the platinum wire, then commercially used for leading in conductors for incandescent lamps.

We thought that if we could make the conductor in such a form that its surface of contact with the glass would be very large in proportion to its thickness, any heat developed would be more easily absorbed by the glass without cracking and the relative expansion by heat of the metal and glass would be less, and so we started out to make these platinum ribbons to conduct the current through the seal for these series incandescent lamps. Many hundreds of these lamps were commercially exploited.

When we found that we were successful in that attempt we grew bolder. We said "Now, if the platinum in the sheet form will carry those heavier currents and not crack the glass seal, why not take some other metals, iron and copper," and then we tried thin copper ribbons and sealed them in the manner shown by Mr. Houskeeper this morning, without however thinning the edge, and we were very much astonished to see that the seals did not crack; they seemed all right, but after a while the air leaked in and destroyed the vacuum.

Mr. Houskeeper has told me this morning why we failed and I want to pay my tribute to him for this lesson.

I think that the method of sealing he has shown us today is a great step ahead in the art, particularly as it will enable us to manufacture larger electron tubes for the purpose of rectifying alternating currents of magnitude.

C. H. Sharp: With reference to the paper of Messrs. Howell and Schroeder I wish to call attention to one statement which I think should be added, and that is that 500-hour test criteria apply to, I believe, the Lamp Works and not necessarily to other lamp testing organizations which may use a different basic life value for determining the efficiency at which lamps are to be operated on life test.

Mr. Howell has been connected with the manufacture of incandescent lamps longer than almost any other man in the world. He has a familiarity with the history of lamp manufacture, with the romantic history of that art which few, if any, other men possess. It would be very desirable if we could have a record of Mr. Howell's knowledge and recollection of the circumstances of the evolution of the lamp; of the troubles, of the successes which the incandescent lamp manufacturers have experienced in the course of all the years of the development of this art.

A. L. Atherton: The very important work that Mr. Houskeeper has described opens up many possibilities. In thinking over the possibilities, a question comes up which I would like to ask. Some applications for this type of seal will doubtless require materials other than copper on account of chemical limitations. In trying to bond other metals to glass there has been some experience with what seems like an electrolytic action by which gas bubbles are evolved at the contacts. This is particularly true with metals like nickel which have other advantages over copper. I would like to ask Mr. Houskeeper if this sort of thing has been encountered in the work which he has referred to with metals other than copper, and if some preventive methods have been devised.

W. G. Houskeeper: In answer to the last question as to the sealing of other metals than copper into glass, if I understood the question correctly it was a question of the evolution of gas bubbles between the metal and the glass. That can be very satisfactorily taken care of by giving the metal a heating in vacuum before the glass is applied. If sheet nickel, for example, be maintained at approximately 800 deg. cent. for ten or twenty minutes in vacuum you can apply the glass to the surface any time in several weeks without bubbles between the glass and the nickel.

THE STANDARDIZATION OF ELECTRICAL MEASURING INSTRUMENTS*

(Brooks), Swampscott, Mass., June 29, 1923

W. B. Kouwenhoven: On the fifth page of Mr. Brooks' paper, where he lists the proposed types as portable and switchboard instruments of various grades, I think that it would be advisable to add a third grade under the portable class. This third grade might be known as laboratory instruments. It should include instruments that can be used in rough, ordinary work; something better than an indicator but not a precision instrument. I feel that a sub-classification giving the type of controlling force employed in the instrument would be of value and interest to the user. The controlling forces found in common use in deflection meters are:

1. Resisting force of a spring; 2. Torsion of a filament; 3. Attraction of gravity; 4. Attraction or repulsion of permanent magnet.

On the eighth page, item d under heading 8, where Mr. Brooks discusses the effects of the external field on the deflection of the instrument, I think the last clause of that paragraph might well be modified to read as follows: That the external field be placed in such a location as regards phase and position that it will cause the maximum error in the instrument.

One point that I think should be added to these specifications, is: What is the effect on the deflection of standing under load for one hour? A great many instruments change considerably on that test.

Another requirement that might be added is that an instrument should be insect proof.

C. M. Green: There is one point at which I have been very much perplexed in connection with the use of instruments and in this connection I would particularly refer to "Standards of the Institute of Electrical Engineers" under date of 1922, page 25, "Kinds of Current," Rule 3104—Direct Current, 3108—Pulsating Current and 3112—Continuous Current. To my mind these apparently are normally rules or definitions without any actual defining.

It seems to me that our book of standards is in a most deplorable condition in reference to the definition of the various kinds of currents, and if there is a single member here who can from these rules determine definitely where direct current leaves off and a pulsating one begins, I surely should appreciate it if he would help me out.

I have heard complaints regarding some half-wave tungar rectifiers not fulfilling their rating, the rectifier being rated at 6 amperes and the customer claimed that it gave 11, which was more than he wanted. However, with two ammeters connected in the circuit with the batteries which are being charged from the half-wave tungar rectifier, the d'Arsonval type of instrument,

*A. I. E. E. Journal, 1923, Vol. XLII, July, p. 713.

which gives the average value of the current which is effective in charging the battery, recorded 6 amperes, the rating of the outfit, whereas an inclined-coil instrument giving the r. m. s. value of the current, or its heating value, recorded 11 amperes. Can anyone tell from our rules 3104 and 3108 whether the current flowing through this circuit was a direct or pulsating current? For all intents and purposes the battery was being charged just as effectively at 6 amperes as though it had been from a normal d-c. source, and as such was the current flowing into the battery a direct or pulsating one as determined by the above rules?

A. E. Kennelly: I would like to call attention to one point, namely, that if this work is going to be serviceable to the American Institute of Electrical Engineers, it must be serviceable to our fellow groups of engineers in other countries than this, and therefore it must be expressed in one and the same system of units. The units employed in these specifications are in the main metric, as I think we will all agree that they should be, but there are a few of the specifications such as for example appear in the immersion problem on the ninth page, which call for immersion under three feet of water.

It seems to me that in order to make the specifications universally suitable to all possible parts of the world, one and the same system of units should be used throughout.

J. R. Craighead: On the fifth page of Mr. Brooks' paper he states that the Committee was fully agreed that the word "indicator" is obsolete as indicating an instrument of somewhat inferior accuracy. It has not seemed to me that the word is obsolete in that sense. I was glad to note that Professor Kouwenhoven, requested that there should be inserted in the table on the fifth page a place for an instrument which would come between the grades indicated. He said that it should have an accuracy "better than an indicator, but somewhat less than a precision instrument." The language would suffer a loss if we cut out the use of the word "indicator," for that purpose because its use is active at the present time.

On the seventh page the definitions of the circuits of indicators and instruments are so drawn that they do not refer to definite mechanical parts of the apparatus; rather, they refer to the circuit connections. I cannot say that this is necessarily objectionable, but it is a fundamental change from the way that such definitions have usually been made. That is, if we build a five-ampere instrument and set it on the shelf and we have a current transformer for use with that instrument, in any given case the transformer may or may not be used. If we use the instrument alone, the current circuit of the instrument is then both the indicator circuit and the instrument circuit. The instrument and the indicator are identical. If, on the other hand, we connect this circuit to the secondary of the current transformer, the circuit becomes the indicator circuit, and it is no longer correct to refer to it as the instrument circuit. The primary circuit of the current transformer then becomes the instrument circuit.

Similarly in attaching a millivoltmeter to a shunt, the instrument becomes the shunt plus the parallel circuit made by the millivoltmeter winding. The indicator circuit is the millivoltmeter winding, but if you use the millivoltmeter direct, the millivoltmeter winding becomes the instrument circuit.

I am mentioning this to call attention to the action this committee has taken and to note that it is considerably different from previous practise.

Paragraph 8 on the eighth page is divided into a, b, c and d. The word "greatest" implying a maximum error is implied in paragraphs b, c and d but omitted in paragraph a. It would seem that as this case is strictly parallel to the others the error should also be defined as a maximum.

Under paragraph d the statement regarding the location of the field is not quite complete. That is, if we form a field of five gausses and intrude an instrument into that field, the field is then more intense than five gausses at some points and less intense at other points. There should be some other closer definition as to the point at which the five gausses are to be maintained in order to get a definite thing which can be repeated at different places. That is, the resultant field would be very largely affected by the size of the coil used to maintain it, and by the exact way in which the coil was placed with relation to the instrument itself.

H. B. Brooks: I am sure that the favorable comments made by Dr. Kouwenhoven and Dr. Kennelly are appreciated by the Subcommittee which has had the task of preparing these specifications.

Dr. Kouwenhoven suggestion for a third grade of portable instrument is in line with recent developments. The General Electric, Weston, and Westinghouse companies have all produced smaller portables for general purposes, such as trouble location.

The comments of Dr. Kouwenhoven and Mr. Craighead about the specification with respect to the effect of external field are very good and the specification should be modified accordingly.

In regard to Dr. Kouwenhoven's question about the rating, it may seem puzzling that we have two standard temperatures for instruments. The explanation is that the twenty-degree requirement refers to instrument performance; that is, to accuracy and other operating characteristics, with the exception of ability to stand overloads. The forty-degree requirement refers to the rating; that is, an instrument must be capable of carrying the specified load for the specified time with the external temperature at the unfavorable point of forty degrees centigrade.

I agree with Dr. Kouwenhoven's suggestion, at least as far as portable instruments are concerned, that there should be a requirement limiting the permissible change in accuracy caused by standing in circuit. In the case of switchboard instruments it might be sufficient to specify that they should stand in circuit with a given load for say one hour before the accuracy test is begun.

Mr. Green reports the interesting circumstance that two perfectly correct ammeters connected in series in the output from a rectifier may show values as different as six and eleven amperes. It is unfortunate that there is not available in standard text books a good discussion on the subject of the measurement of pulsating currents. There are only two things in print about this, of which I am aware. The first is a discussion by Mr. P. MacGahan and was published only for the engineering department of the Westinghouse Company. The second is an article on "Selecting Ammeters for Various Current Measurements," by Mr. V. H. Todd of the Westinghouse Company, in *Electrical Review* (Chicago), October 30, 1920. It is really quite important to to choose the proper ammeter and it depends upon whether you are interested in the effective value of the current or in the average value. If you are charging a battery with a pulsating current you want an instrument which measures the average value; when operating lamps or heating devices an ammeter which measures the effective value should be used.

Dr. Kennelly is quite right in saying that if American specifications are to be most useful for American engineers, they must also be suitable for foreign engineers, and I am sure the committee will make the necessary corrections.

As to Mr. Craighead's comments about the word "indicator," I believe that word is no longer used in instrument catalogs or in technical articles, but I am glad to be corrected if such is not the case.

There is a very good reason for using the word in the sense that the committee proposes. We have tried in vain to find another English word which will express the thought and still leave the word instrument for the complete measuring equipment; that is, the indicating device with all of its accessories.

As to the suggestion of Mr. Craighead that the word "greatest" should appear on page 8 in connection with the definition of temperature influence, I would say that to the best of our knowl-

edge temperature effects on instruments within a range of a plus or minus ten degrees centigrade are always linear. For that reason we did not feel it necessary to put in the word "greatest," but the effect of frequency, for example, is often quite different from linear, and the effect of the other quantities may also be safely specified by putting the word "greatest" in the three definitions.

PELLET TYPE OF OXIDE FILM LIGHTNING ARRESTER*

(Lougee), Swampscott, Mass., June 29, 1923

K. B. McEachron: The pellet arrester represents an extension of the oxide film principle in an ingenious manner. The problem of making, commercially, small pellets of lead peroxide, and coating them with litharge has been solved in a satisfactory manner.

In design it is possible to increase the discharge rate by increasing the number of pellets in parallel and to increase the operating voltage by increasing the number of pellets in series. The arrester is simple in construction and offers some advantages over the cellular type in the matter of assembly.

A large number of tests have been made on the arrester while in the developmental stage and also after being put in production. A volt-ampere curve (expressed in r. m. s. values) taken on a group of 3000-volt arresters using the discharge from a lightning generator is shown in Fig. 1. It will be seen that the

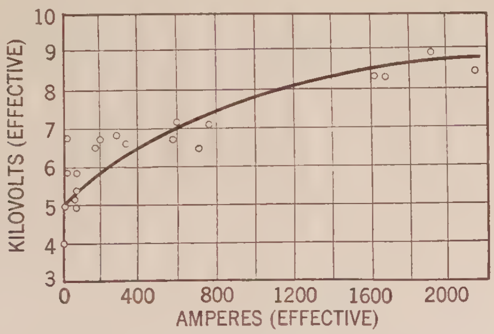

Fig. 1—Volt-Amperes Characteristic of Pellet Arresters (3000-volt)

voltage across the arrester at currents below 100 amperes lies between 4 and 6 kv. This value is practically the same as obtained from other good arresters of the same voltage rating. With an instantaneous current, 1500 amperes, the voltage is approximately 8.5 kv. This voltage is considerably lower at these higher currents than any other arrester we know of.

It is probably true that under lightning conditions in service on a distribution circuit, that most of the discharges will be of low current value, but the reserve capacity is present in the pellet arrester if needed.

V. E. Goodwin: It has been a source of gratification to me to note the interest and progress which has been made in recent years in the methods of test and in the development of lightning arresters. This is a line of work in which we can have no prejudice and no favorites.

It is only a few years ago that arresters were tested with a static machine and Leyden jars. A little later the lightning generator was brought out with larger condensers operated at 100 kv. and later at 250 kv. At that time we entered what might be termed the wood splitting age as blocks of wood could easily be shattered by discharges of this magnitude. Recently we have all heard of the 2,000,000-volt generator.

Great improvement has likewise been made in the methods of measurement of these impulse voltages. First these measurements were made with needle gaps and later by sphere gaps which were more capable of measuring the crest values of voltage. Recently we have been able to study the decrement as well as the crest values of voltage. This decrement in voltage is of great importance as it gives a fair idea of the value of the voltage at any time during the discharge of the arrester. This is accomplished by means of gaps having greater and known time lags, such as gaps with shunt capacitance and resistance.

A few months ago we had an excellent paper by Mr. Atherton describing the development of a new type of valve arrester. Today we have this paper by Mr. Lougee which gives a general description of pellet type oxide film arrester. This is another valve type arrester. Valve type arresters have ideal characteristics from an operating standpoint as they allow little or no dynamic current to follow the lightning discharge. Any flow of dynamic current is objectionable and should it continue for over a cycle or so a serious interruption to service is liable to follow. The chief difference between it and the standard oxide film arrester is that the cell element in the former is the individual pellet. The operating voltage per cell is much lower which allows of great flexibility in design.

The pellet design has an excellent volt-ampere characteristic, as Mr. White has just shown by the curve on the blackboard. This means that the arrester has low impedance to lightning impulses and will handle heavy discharges without excessive rise in voltage. The arrester also has a high dynamic voltage failure point. This is another important consideration since arresters are frequently called upon to function during line troubles when the line regulation may be momentarily very bad.

C. P. Steinmetz: The pellet type of oxide film lightning arrester, adequately fills a gap for which no economically suitable lightning arrester was heretofore available, namely that of primary distribution circuits of 2300 volts and over, up to 13,200 volts and more.

The first great advance in lightning arrester engineering was made by Alexander J. Wurtz, in his investigation of the non-arcing metals. This gave us the multigap lightning arrester. Its characteristic is, that the dynamic which follows the static discharge is cut off at the end of the first half wave, and therefore does not disturb the circuit. The multigap arrester remained the standard of the best type of arrester until electric transmission voltages had increased to values at which arcing grounds could exist. Then the multigap arrester failed, for these higher voltage circuits, as it is almost instantaneously destroyed by an arcing ground, and for sometime the protection of transmission lines against lightning appeared almost hopeless indeed.

The problem was solved by the development of the aluminum cell arrester. Its characteristic is, to let the static pass freely, but not to allow the dynamic to follow at all. Therefore the aluminum arrester can take care of arcing grounds for a reasonable length of time. It quickly became the standard of excellency, used wherever protection was of importance. Its only disadvantage is, that it requires attention, that is, systematic charging. This disadvantage was overcome by the development of the oxide film arrester. This also is a counter-e. m. f. or valve type of arrester and like the aluminum cell, has the same high discharge rate, the same ability to cope with arcing grounds, and the other good features of the aluminum arrester, but it requires no attention. It therefore rapidly replaced the aluminum arrester.

For low voltage primary distribution circuits, such as 2300 to 13,200 volts, and more particularly for the protection of smaller apparatus, such as lighting transformers, distributed on such circuits, the standard forms of aluminum and of oxide film arresters were not economical, in view of the relatively low cost of the individual protected apparatus. The problem therefore arose, to produce an arrester of the type of oxide film, which is economically suited for these circuits. This has been solved by Mr. Lougee in making this arrester economical for lower

*A. I. E. E. Journal, 1923, Vol. XLII, October, p. 1019.

voltages by putting it into pill form, as we may say. But though in pill form, it is a real lightning arrester; it has the same high discharge rate, the same self-healing qualities, etc. It has lost none of the advantageous features of the standard oxide film arrester.

In its present form, the pellet arrester is a development which had been practically completed some years ago; with apparatus as lightning arresters, where the final decision of excellency after all is the practical experience, it is our fixed policy to try it out thoroughly for years, first in our laboratories, and then in industrial circuits, by the installation and operation of numerous arresters, so that, when we finally present it to you, our statements are not the expectation and hope based on limited laboratory experiment, but are the result of years of experience on hundreds of arresters in real industrial service.

A. L. Atherton: There is one interesting and very significant point which is illustrated, or rather emphasized, by the description by Mr. Lougee of this new form of the oxide film lightning arrester. That point, fundamental to the lightning arrester industry, is that the manufacturer for whom Mr. Lougee speaks, and the one for whom I am speaking, the Westinghouse Company, are both striving in lightning arrester development toward pretty much the same thing.

This is important in lightning arresters because some other manufacturers are not striving toward those same ideals. The special significance of the basic agreement of these two companies lies in the fact that both are fundamentally manufacturers of what we might call primary or working equipment, and are only suppliers of lightning arresters and other accessory types of equipment because it is realized that these are necessary if the systems for which apparatus is supplied are going to perform in such a way as to promote the growth of the electrical industry as a whole.

Lightning arresters are a minor part of our business. The engineers who develop and design lightning arresters are charged primarily with the problem of protecting apparatus and only secondarily with the provision of apparatus which will be a profitable business.

That the two organizations which approach the problem from this broad viewpoint aim at the same characteristics as a fundamental, is significant because it is a rather clear proof that those characteristics are the right ones. There are quantities of devices made and sold and used with the idea that they are protective devices, but in the design of which all of the principles that have to do with correct protective equipment are completely neglected.

This point is stressed because I believe that the cause of the use of these inferior devices is the lack of general understanding of the requirements for lightning arresters to give performance. I don't think very many people make poor investments knowingly and willingly.

In this connection I would like to make a suggestion in regard to the presentation of information on lightning arresters. Such information should be in very definite, specific, quantitative terms, which it has not very generally been in the past. When we speak about resistance of an arrester, it is better to say so many ohms than to say it is a low resistance. This sort of information is lacking in Mr. Lougee's paper, probably justifiably, but was supplied to some extent in one of the discussions.

There are one or two points in connection with the arrester itself on which I would like to comment. Every one has found it very difficult to make solid dielectrics in which the breakdown voltage is reliable, particularly when the voltages required are low. Mr. Lougee probably has a very vivid realization of this from work in development, to a reliable point, of the varnish film on the older form of oxide film arrester. In this case the voltage that was aimed at was something like three hundred volts breakdown per film.

The dimensions of the pellet arresters are not shown, but judging from the cut, Fig. 5, there is a column of pellets, something like six or seven inches long, in the 2300 volt arrester. This would mean something like sixty pellets in series, or sixty miniature oxide film cells, as they are called by Mr. Lougee, in series for 2300 volts.

This represents a normal voltage rating of forty volts or so per cell and means that the breakdown per dielectric film has to be of the order of forty or fifty volts to give a reasonable total breakdown voltage.

It certainly is an accomplishment if solid material has been provided which is reliable in breakdown at voltages of that order. Of course, the curve given in discussion has no bearing on this point since it indicates only characteristics after breakdown.

The matter of life of arresters under discharge, referred to on page 1020, is one of particular importance. More definite information about the conditions in the tests referred to would be of interest.

An arrester, even of the distribution type, has to carry several hundred amperes and sometimes even a thousand amperes of surge current. Laboratory tests which we have made indicate that the life of any kind of arrester varies very greatly with the current. Types that fail after two or three thousand discharges, at an overload condition of 5000 amperes, seem to last indefinitely with currents of the order of two hundred to five hundred amperes. The reference in the footnote describes tests in which the currents are of the order of fifty amperes. It would be interesting to know further about these tests, in order to know their significance, and to have data on life under conditions which approach service conditions in severity.

This point is of particular importance in the type of arresters described. The gradual change toward a condition of open circuit, which is taken care of in the older type with the cell testing device, presumably takes place in this arrester also, since the same chemical action is the basis of performance in both cases. After some length of service it would seem that this gradual change will result in an arrester which is practically open-circuited but which appears from visual inspection to be intact and operative. Inspection by testing is not feasible with distribution arresters. The idea is pretty well established that lightning arresters, particularly for this class of service, must indicate very clearly whether operative or not, even by an inspection from the ground. It would be interesting to know whether this has been taken care of and how.

E. R. Stauffacher: On the first page the statement is made—"To make a lightning arrester these covered pellets are placed in an insulating tube, of say, porcelain, and bare electrodes attached to each end of the tube in contact with the pellets."

I should like to inquire whether the construction of a commercial arrester is such that the wire which connects between the line and the column of pellets goes directly to the column or whether there is an air gap interspersed. Probably I can illustrate this on the board. In the construction as shown in A, or as shown in Fig. 2.

If the B construction issued, the leakage would be constant, although it would be only of a very small amount, "less than one milliampere when new, and contrary to expectations, continued service does not increase it."

However, if there should be a gradual deterioration of these pellets, or if the leakage remains the same as when new and you had a great many of these arresters, for example, several hundred connected on a distribution circuit, there will be a condition of a multitude of slight grounds on this circuit. This would cause considerable annoyance when every effort is being made to keep the system clear of grounds and confusion would result if each circuit had a ground detector connected to it.

As I understand it, this is primarily a distribution type of arrester used for the protection of transformers at industrial

plants and at small pumping plants, for example, such as exist in considerable numbers in Southern California.

The statement is made that the tests of the pellet arresters show practically the same characteristic as that of the oxide film cells with which we are so familiar. However, is there any quantitative value which could be placed upon them? The standard oxide film cell has a certain discharge capacity. A column of pellets has another certain discharge capacity, depending upon the diameter and the length. What is the relation between the two? In other words, would it be possible to substitute a number of these pellet type arresters for one of the oxide film arresters to protect the transformers at a large capacity substation? At some of our smaller substations it is found more convenient to mount an arrester on a pole. If several of these distribution type pellet arresters could be mounted in parallel in place of the ordinary oxide film arrester, probably the construction would be much cheaper.

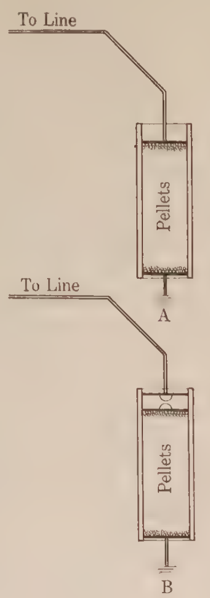

Fig. 2

I would appreciate very much hearing from Mr. Lougee, or any of the discussers as to whether they have any information on this point.

N. A. Lougee: Mr. Atherton has asked several questions relative to the protective value and life of the pellet arrester. While it may be of interest to know that in spite of so many miniature cells in series, the 60-cycle or low-frequency voltage breakdown is very sensitive, it is the impulse breakdown which we are interested in with lightning arresters. The curve shown by Mr. McEachron gives the maximum voltage drop across the arrester during high-voltage impulse discharges with large values of current. This voltage, measured by a sphere gap records the maximum voltage appearing across the arrester, and which may be either the initial breakdown voltage or the voltage drop across the arrester during discharge. The results which have been obtained as illustrated by this curve show unusually low voltages, insuring a high degree of protection. As stated in the paper the sensitivity of the arrester, although composed of many films in series, may be due to the fact that the litharge film acts principally as a spacer and not as a solid dielectric.

Mr. Atherton's reference to a former paper may be somewhat misleading. Some of the tests referred to in this paper were surges of arcing ground characteristics and were used to help determine the life of the regular *OF* arrester. The lightning generator has since been developed and is the criterion, of course, in all types of tests. The pellet type has successfully withstood thousands of discharges on this circuit. This older test referred to, the arcing ground, is still of value, as there are very few types of lightning arresters which can successfully withstand this sort of test for any length of time.

Extensive laboratory tests show that testing will not be required. This is apparently due to the number of pellet cells in parallel and because they are affected even less by discharges than the regular *OF* cells.

Mr. Stauffacher asked if a series gap is used. It is used, even though the leakage current is extremely minute, and it is used principally to prevent grounding the circuits and to eliminate the small ground currents which would occur. Although the pellet type was developed primarily for low voltage distribution circuits, extensive tests prove that it is the equal of the *OF* type, and we see no reason why it can not be used to protect any type of apparatus and on any type of circuit.

A CONTINUOUS CURRENT GENERATOR FOR HIGH VOLTAGE*

(Bergman), Swampscott, Mass., June 29, 1923

P. L. Alger: The chief interest of Mr. Bergman's paper is in the commutation of the machine, that is, the chief theoretical interest. Mr. Bergman is building a machine for proper commutation. To get the commutation we must have low reactance and we must have a very definite commutating flux to make the voltage induced by the flux exactly overcome the voltage of the changing current. Unless a machine is very perfectly compensated, you cannot hold that flux just right because when the load changes, the armature reaction makes the neutral point shift; so the first thing is to obtain very perfect compensation. Mr. Bergman has done this. Another thing that helps commutation is his distributed field winding, as by this means he has a relatively gradual rise of flux on leaving the neutral, as compared with the salient pole winding.

Thus, by building a machine with perfect commutation he has made a machine which will stand anything almost in the way of speed or load variation without trouble and it appears to me that this scheme is also applicable to low-voltage continuous-current machines with similar advantage.

It seems to me the philosophy of the matter is that the machine with salient poles is one which has maximum space factor and maximum flux per pole, whereas Mr. Bergman's distributed winding machine is one which has a maximum fixity of wave form; that is, the flux is exactly placed by the winding instead of being left free to shift to and fro. I believe this idea of giving more weight to flux distribution than to space factor and total flux will grow in time and that all machines that are capable of compensation will ultimately change over to the distributed winding instead of the salient pole type.

H. Lemp: Mr. Bergman mentioned another form of producing unidirectional currents for high voltages, referring to kenotron or vacuum tubes, but he omitted to make any reference whatever to the mechanical synchronous rectifier. While I do not wish to put in a plea for myself, I would like to plead for a child of my brain which has survived in the form of a mechanical rectifier for producing high-voltage unidirectional currents, and is particularly useful for X-ray work.

With the advent of the X-rays, there arose a demand for a continuous source of excitation of high voltage susceptible of furnishing large quantities of unidirectional currents; various forms were tried, and the Holtz influence machine which was at that time considered the most desirable source of excitation, was found ineffective on account of lack of sufficient energy behind it, particularly in wet weather, and it was then that the mechanical rectifier was developed by me in order to produce large quantities of these unidirectional currents unaffected by weather conditions and of sufficient high frequency to give a continuous non-flickering illumination, so necessary for fluoroscopic examinations.

This type of mechanical synchronous rectifier is now used, as is well known, by Cottrell in his method of precipitation of smoke and metallic vapors, and is still used exclusively for X-ray work where more than one hundred thousand volts are required. Below that voltage the hot cathode tube is sufficient to rectify its own supply.

I had recently the pleasure of seeing in Chicago at the factory of the Victor X-Ray Corporation, an improved mechanical rectifier in operation which supplied simultaneously energy to something like ten full-sized Coolidge X-ray tubes which represents a large amount of energy, particularly when one considers that 200,000 volts are used, which is substantially equivalent to sparks of from 12 in. to 14 in.

S. R. Bergman: I think Mr. Lemp's remarks on the mechanical rectifier are very interesting, but its use is limited to

*A. I. E. E. Journal, 1923, Vol. XLII, October, p. 1041.

certain applications; for example, for X-ray work and for precipitation of smoke and metallic vapors.

The mechanical rectifier, however, for producing actual power does not seem very promising. It is very difficult to drive such a rectifier in exact synchronism, particularly when the power factor of the load changes. Since the mechanical rectifier not only changes the direction of the current, but also the wave form, particularly if we wish to derive a steady current, it is obvious that there exists a large differential current which causes sparking, which, particularly on short circuit, becomes so violent that it generally puts the rectifier out of business.

The mechanical rectifier generally gives rise to pulsations, in that respect, showing a similarity to a direct-current generator having two segments per pair of poles corresponding to a pulsation of 100 per cent. One of the objects of the machine which I described in my paper is to give as steady a current as possible. In a d-c. machine, the pulsations decrease with the number of segments per pole; for example, with 90 segments per pair of poles, the pulsations amount to 0.03 per cent. As a matter of fact, the pulsations due to the segmental arrangement of the commutator in a d-c. machine are generally smaller than the variation caused by the pulsation of the flux due to the variation of the reluctance of the magnetic circuit. It is a well-known fact that due to the presence of teeth in the armature, a certain amount of pulsation of reluctance takes place causing variation of the flux. Although, by choosing the number of teeth in the armature properly as compared with the number of teeth in the field, it is possible to limit this variation so as to make it unobjectionable. In a machine of the character which I describe, we manage to keep the pulsations down to 0.1 per cent. I believe it would be extremely difficult to make a mechanical rectifier having so small a variation.

DESIRABLE DUPLICATION AND SAFEGUARDING IN THE ELECTRICAL EQUIPMENT OF A GENERATING STATION*

(Sims), Swampscott, Mass., June 29, 1923.

R. L. Young: Mr. Sims' paper is of considerable interest to engineers outside of the central station field. I hope that many, if not all, of the more important stations and systems will in time arrange their equipment in the excellent manner outlined in the paper.

As an example of the consumer's interest, in telephone central offices the question of a reliable power supply of the special type required is of very great importance and the matter of reserve equipment has received careful study. I remember making a two thousand mile trip for a five-hour conference with Mr. Sims' people on the very questions he discusses.

We have engineered upon the basis that power for telephone offices must be available at all times even under conditions of emergency which may be so severe as to compel suspension of central station service.

It is thus seen that as a user of power we are much interested in what the central stations are doing to insure continuity, since we must supplement their efforts and secure a joint power supply which approaches absolute reliability as nearly as economy will justify.

Although the power supply to telephone buildings may often be considered small to the central station companies, the centralization of equipment in certain of the larger buildings has increased the annual demand to well over one million kilowatt-hours.

Where the duplication and safeguards adopted by the power company are so excellent as those outlined it is only necessary to get two or more independent services from separate generating stations and we appreciate the cooperation received from the power companies.

*A. I. E. E. Journal, 1933, Vol. XLII, July, p. 704.

The Franklin telephone building in Chicago, for example, has been included in a substation loop giving 12,000-volt service in either direction with three generating stations on the loop, and automatic circuit breakers in each lead. In addition there is a separate 12,000-volt direct stub from the nearest substation which stands by continuously.

Where we are fortunate in getting such service, no other reserve is required except duplicate transformer and switching equipment in the telephone building.

In the less favorable cases where only one service or two services from one generating station can be obtained, it is necessary to provide gas engine generator reserve of our own. This has been found very useful on numerous occasions, one of the most recent being during a total suspension of service for several hours a few months ago in an important city within a hundred miles of here. If the feeder reactors of busses and control leads here recommended had been followed this suspension would have been avoided.

Of course, after the central station power is received in good order it is necessary to convert it into different form for telephone use and here all vital machines are duplicated and a storage battery capable of carrying the office for several hours is also provided.

E. S. Fields: In the operation of plants at high load factor the problem of duplication and safeguarding equipment is coupled with those of quick and efficient repairs and prevention of troubles.

For the purpose of facilitating quick repairs and regrouping of equipment it is necessary in the larger stations to have complete sets of detailed connection diagrams for reference of operating and maintenances forces and also a supply of spare parts to cover repairs quickly. Also it is very helpful to have all main and control connections and equipment marked on their terminal boards, etc., to conform with the designations used on the diagrams of connections. It has been found very advantageous to post diagrams of connections close to the apparatus itself and to divide the storeroom up with a particular space assigned to each class of apparatus. The spare parts carried for each piece of apparatus are tagged and marked specifically and a cross reference is given which shows all the apparatus to which this part is common.

The degree to which electrical plant apparatus is free from troubles is to some extent a measure of the thoroughness of inspection and testing. It is very important to have a routine system of these inspections and tests conducted in an intelligent manner and a glance over the reports for even a short time is evidence of the economy of these methods. Such tests cover temperatures, air conditions and insulation resistance of generators, voltage drop on contacts of high-current switches, dielectric strength of oils, etc.

W. F. Sims: The provisions for duplication of equipment covered in the paper take into account the necessity of taking individual parts of the installation out of service for repairs, without unduly affecting the service.

Mr. Fields' recommendation that the operating force be supplied with complete sets of connection diagrams is of great importance, not only for the purpose of facilitating repairs, but also to aid in the insuring of intelligent operation under abnormal conditions. Simplified one-line diagrams of the principal connections posted in convenient locations are a great help to the operating force, particularly in connection with the breaking in of new operators.

It is essential that careful consideration be given to the provisions for duplication in order that the added complications introduced shall not be such as to increase the liability of operating error, and thus to a certain extent offsetting the value of the added equipment.

THE AXIALLY CONTROLLED MAGNETRON[1] (HULL), GASEOUS IONIZATION IN BUILT-UP INSULATION[2] (WHITEHEAD), EFFECT OF TRANSIENT VOLTAGES ON DIELECTRICS —III[3] (PEEK), and TWO PHOTOGRAPHIC METHODS OF STUDYING HIGH-VOLTAGE DISCHARGES[4] (MCEACHRON),

SWAMPSCOTT, MASS., JUNE 29, 1923

F. B. Jewett: I wish to touch upon a point which Mr. Peek has referred to in his concluding remarks and call attention to the curious phenomena which have been observed from time to time in connection with these very high energy transients, which sometimes occur in connection with lightning discharges.

Very frequently in examining pieces of rubber covered wire, such as that used in ordinary telephone work for connecting up subscribers' instruments, pieces of wire through which heavy current discharges have passed, the most curious things have been noticed. In the first place you frequently find long lengths of this insulated wire where the wire itself has not only been completely disintegrated, but where casual observation indicates that the metal of the wire has almost completely disappeared without any visible indication of the rubber coating having been seriously ruptured. There are ruptures, of course, and that has given rise to suggestions such as Mr. Peek has just made as to what curious things might be produced by these enormous mechanical forces which must be for a very short instant of time developed in the wire itself. With the apparatus which Mr. Peek has had in hand and similar apparatus, I rather expect that in the next few years we will learn a great many things about matters which in the past have been more or less the subject of speculation.

'or instance, if the metal of the wires were not copper—were not a pure metal, but an alloy—would these enormous forces applied at a time when the metal was in a molten state, or near a molten state, produce extreme examples of those processes which have been developed for producing very high grade alloys from relatively low grade material?

I just mention that as a matter of curiosity because there are obviously a lot of things that we want to know about, which may or can take place under the conditions of these enormous energies dissipated in a very small space of time.

H. Goodwin: There has long been a feeling among practical men that wood arms have some value in connection with the insulation of high-voltage lines, that is, from 11,000 to 66,000 volts. In general, technical men have scoffed at the idea of the wood having any real value as insulation for these voltages. Further, it has been considered that when these arms are wet their resistance is very much reduced, and any insulating value they might have when dry is entirely eliminated. Have your tests gone far enough to show that there may be some insulating value in the wet wood cross-arm in series with the insulators when subjected to a high-voltage steep front wave? Some of your data would seem to indicate that the wood arm may have considerable value, but we appreciate how very unsafe it is to draw sweeping deductions from special tests.

What you have developed on the increase of voltage due to the use of choke coils is of very great interest and confirms claims made by others.

C. J. Fechheimer: I think perhaps that the causes of insulation failure in large high-voltage generators may be attributed to three sources, the first being too high temperature, which may cause the insulation to char and to chafe. This is well known. We have had a great deal of discussion in the Institute on that subject.

The second is mechanical failure which may arise from various causes; with long core machines there is possibility of electrical failure from alternate expansion and contraction, due to changes in temperature. That has not been discussed, so far as I know, at any of our meetings.

The third is the possibility of failure from corona, either external to the insulation or internal.

With regard to the second source, I may say that at the Westinghouse Company we are conducting a large number of tests to determine how serious may be the danger of failure from alternate expansion and contraction and we hope that within the course of a year or less we shall be able to present before this Society the results of our investigation. At present, I would rather not speak of that as it does not pertain to the subject.

On the subject of the possibilities of failure from corona that Dr. Whitehead's covers, there are two or three points to which I want to call attention.

I think the principal conclusion which one may reach is that the danger from failure in well insulated coils having a large percentage of mica is extremely small. Those who have been skeptical in this regard may now feel quite safe that their machines will not fail. I know that some years ago when mica was not used to the extent that it is today, treated cloth or paper were the chief constituents of the insulation; the insulation failed undoubtedly from internal corona or possibly external corona.

Even when coils are insulated with mica we have found that after they were in service for a number of years, the insulation on the outside—which is usually paper for mechanical protection—was pitted. But immediately after removing the external layer of paper, where the mica appears it was found there was no pitting whatsoever; the mica was in as good condition as when it was placed upon the coil. In other words, for ordinary service up to, say, around 15,000 volts, there is practically no danger from breakdown due to corona.

That is one conclusion which one might infer from the paper, but the other conclusion is that the corona loss with mica insulation is very much less than with fibrous material. In other words, we have eliminated danger from breakdown when mica insulation is employed, by two means; we have first reduced the internal corona loss, and then we have, since we use mica, practically eliminated any further danger of breakdown because mica will successfully withstand corona discharge for indefinite periods.

J. F. Peters: Mr. Peek's paper indeed is very interesting in showing us the behavior of very high-voltage circuits and the apparatus described in the paper undoubtedly will be of very great value in obtaining data for high-voltage engineering. I feel, however, that some of the conclusions drawn from the tests have been made rather loosely.

For instance, in the second column of the third page, where the author is discussing the impulse ratio of sphere gaps with various series resistances he states, "The effect of the series resistance increases with increasing wave front. This arrangement may be used, therefore, to indicate the duration and wave front of transients."

It has been very definitely proven that the delay of a sphere gap with series resistance is due to the time required to charge up the spheres as a condenser through the series resistance. That being the case, the delay is fixed almost entirely by the duration of the surge and is practically independent of the wave front. The wave front and duration to a very limited extent are proportional, but the duration can be varied over a very wide range without materially affecting the wave front.

For instance, taking the curve shown in Fig. 3 and the constants there given, the equation of that curve is:

$$E_0 \ (\epsilon^{-0.152 t} - \epsilon^{-0.173 t})$$

where ϵ is the base of naperian log and t is time in microseconds.

1. A. I. E. E. JOURNAL, 1923, Vol. XLII, October, p. 1013.
2. Published in pamphlet form only.
3. A. I. E. E. JOURNAL, 1923, Vol. XLII, June, p. 623.
4. A. I. E. E. JOURNAL, 1923, Vol. XLII, October, p. 1045.

ϵ^{-} to the minus 173. t fixes the wave front almost entirely while the other factor ϵ^{-} to the minus 0.152 t—fixes the time or tail of the wave.

If the capacitance there used were double and R and L remained the same, then the exponent fixing the wave front would be 173.1 as compared with 173, whereas the exponent fixing the length or time of the surge would be 0.075 instead of 0.152. In other words, the duration is practically doubled, where the wave front is not modified or is modified very slightly.

That being the case, it is obvious that the impulse ratio would be different for the conditions with a larger condenser than it is for the small condenser. So that the spark gap for the given resistance really gives wave front only for some particular quantity of charge.

In connection with the author's investigation of strings of insulators in series with resistances shown on the fourth page, which have characteristics similar to the needle gap, the author states at the top of the first column on the fifth page: "Incidentally these tests show how useless a high-resistance arrester is."

Although I entirely agree with the author on the ineffectiveness of a high-resistance lightning arrester—it is not clear how these tests prove the point. In the first place, a resistance type arrester as usually constructed consists of combinations of resistance and spark gaps in series and has characteristics similar to those shown on the third page, and for moderate resistances the impulse ratio would not be serious. My belief in the ineffectiveness of the high-resistance type arrester is not due to its large impulse ratio but is due to its limitation of current that it will drain from the system when it does function.

Referring to Mr. Peek's conclusion, his last conclusion in the first column of the eighth page is: "In measuring lightning voltages resistance must not be used in series with sphere gap. Resistances so placed give the sphere gap all of the time lag characteristics of the needle gap and the spark-over voltage varies with the wave front."

Whether a resistance in series with a spark gap is at all objectionable or not depends on the relative value of that resistance as compared to the capacitance of the spheres. A certain amount of resistance may be desirable. We all know that if a voltage is abruptly applied to an inductance and capacitance in series where the circuit is not critically damped, the voltage on that condenser will overshoot. A sphere gap with no series resistance is just such a circuit.

The author shows by some of his tests that an inductance located at the open end of a line gives a large increase in voltage due to reflections, and in connection with those tests he finds that by shunting these inductances by resistances, the reflections are very much reduced, and he concludes that "In general, inductances to be safe should be shunted by resistances."

The usual installation of inductance (reactances) is not at the open end of lines. The only inductances that have a legitimate right to be located at the open end of a line are those used in connection with lightning arresters, and when used in connection with lightning arresters, the better reflector they are the more effective will be the lightning arrester.

R. H. Marvin: I was particularly struck by Mr. Peek's experiments with regard to resistance in series with the sphere gap.

It is, I think, generally recognized that wooden construction is of great value in reducing lightning disturbances. I think the general feeling has been—I know my own has been—that its value in this case was not so much in preventing flashover, as in preventing a dangerous arc from following, or hastening the extinguishing of the arc after its occurrence. It would appear from these experiments that we have a still further action in actually preventing the flashover of the insulator and so reducing the number of disturbances. Of course, it is true also that we may have this action in limiting the current after the arc has started.

It is also interesting in this connection to consider the effect of ground resistance. We all know that the resistance of the earth varies widely with the amount of moisture in the ground, and it seems entirely possible that even with metal construction the resistance of the earth may have some effect in determining flashovers from lightning voltages.

J. Slepian: The phenomenon of time-lag in the electrical breakdown of dielectrics has been rightly attributed to the necessity of a certain energy input for converting the dielectric from the insulating to the conducting state. Since electrical energy input is determined by the product of potential, current and time, we see that in all cases time is necessary for breakdown.

The sphere gap in air is known to be extremely fast in its breakdown, and for most purposes may be considered instantaneous. However, we must not forget that actually a finite time is required, and when, as Mr. Peek does in his paper, we are considering things happening in 10^{-8} seconds, we must inquire whether the sphere gap is sufficiently "instantaneous" for its time of breakdown to be negligible I shall show that to bring a sphere-gap into a highly conducting state something of the order of a micro-second is necessary. This being the case, the calculated steep front of the wave shape shown in Fig. 3 of the paper has no actual significance. The gap G of Fig. 1 does not break down fast enough for the voltage on the resistor R to build up at the rate indicated in Fig. 3.

The theory of conduction in gases is now in a highly developed state, and we may make calculations in this field with great confidence in the order of magnitude. I shall now calculate the time of breakdown of the gap G.

To begin, what energy is necessary to make the gap conducting? Before this can be answered we must state more precisely the degree of conductivity the gap is to attain. I assume that in Fig. 3 a four cm. gap was used which breaks down at about 100,000 volts. With a resistance of 5000 ohms, this will give 20 amperes after complete breakdown. Since in calculating the curve of Fig. 3 the volts taken by the gap are assumed negligible against the 100,000 volts, I shall assume that 1000 volts are taken by the gap when carrying the 20 amperes. This defines the degree of conductivity attained by the gap.

The current in the gap is carried by ions, that is, positively and negatively charged particles into which formerly neutral molecules of the air have been broken. The negative ions will be electrons which have a very much greater velocity than the positive ions. Hence, practically all the current will be carried by the negative ions.

Since the current will be given by the product of the charge per cm. of gap carried by the electrons and the velocity with which the electrons move, if we know the velocity, we can determine the charge. Referring to Townsend, "Electricity in Gases" p. 180, we find that the velocity for a gradient of 250 volts per cm. is about 700,000 cm. per sec. This gives

$$\frac{20}{700{,}000} = 2.9 \times 10^{-5} \text{ coulombs per cm. or for the whole 4 cm.}$$

of gap 11.1×10^{-5} coulombs as the charge carried by the electrons.

Now, to separate an electron from a neutral molecule requires a certain amount of energy. This energy has been fairly accurately determined, and is commonly expressed as the voltage, called the ionizing potential, through which an electron must fall to attain this energy. The ionizing potential for air is about 15 volts. Hence the energy necessary to produce the 11.1×10^{-5} coulombs of electrons in the gap is $15 \times 11.1 \times 10^{-5} = 1.67 \times 10^{-3}$ joules. This is about 1/12 of the energy which leaves the condenser in the first two hundredths of a micro-second, as shown in Fig. 3.

Now although 1.67×10^{-3} joules is the energy necessary to

produce the assumed degree of conductivity of the gap, this is not a measure of the total energy which must be put into the gap, for the larger part of this energy goes into produicng heat, and only a small part into producing ionization. To get an idea of the relative proportion, we must consider the mechanism of ionization in more detail. An electron will ionize a molecule if it collides with it after having fallen freely through fifteen volts of potential. Now with the largest mean gradient in the gap, namely, with the initial 100,000 volts acting on 4 cm., or a mean gradient of 25,000 volts per cm., this means that the electron will have to fall freely through a distance of $\frac{15}{25{,}000}$ or 60×10^{-5} cm. But the mean free path of an electron in air is only about 5.7×10^{-5} cm. Hence very, very few electrons will fall freely through the necessary 60×10^{-5} cm. Practically all of them will collide with molecules before they have fallen through this distance and give up there energy as heat instead of as ionization. The actual proportion which will produce ionization may be determined by the formula given in Townsend, "Electricity in Gases," pp. 292 - 293. This gives, on substituting,

$$e^{\frac{60 \times 10^{-5}}{5.7 \times 10^{-5}}} = 10^{-4.6}$$

Thus an electron will collide with molecules $10^{4.6}$ times with an energy corresponding to a fall through the mean free path, for each time it collides with a molecule with energy sufficient to ionize, corresponding to a fall through the distance 60×10^{-5} cm. We conclude then that

$\frac{5.7}{60} \times 10^{4.6} = 4 \times 10^3$ times as much energy will go into heat, as goes into ionization. If this proportion were kept up, $4 \times 10^3 \times 1.67 \times 10^{-3} = 6.68$ joules would have to be put into the gap to produce the desired ionization. and at 10 amperes, 100,000 volts, this would require, 6.68×10^{-6} seconds.

However, after some ionization is produced conditions become more favorable for further ionization, since portions of the gap become charged and cause the electrostatic field in the gap to be distorted, the gradient being increased near the electrodes, and reduced at the center of the gap. In the stronger fields a larger part of the energy spent will go into ionization, so that the total energy which must be put into the gap will be reduced. This does not help out very much on the time of breakdown, however, as the ions which are produced in the stronger portions of the field must move into the weaker portions before full conductivity can be obtained. Now, for a gradient as high as 25,000 volts per cm. the velocity of the electron will be nearly 10^8 cm. per sec., but the velocity of the positive ion is very much less, so that time of the order of micro seconds must elapse before the ions move from the strong field, where they are generated rapidly, to the weak field.

More convincing, perhaps, than the above calculations, are actual experiments. A. Leontiewa, in *Physikalische Zeitschrift*, Jan. 15, 1922. p. 33, describes experiments which show a lag in the breakdown of sphere gaps distinctly greater than 10^{-8} seconds. In these experiments however, breakdown meant merely a luminous discharge, and a discharge of only a microampere may be luminous. To attain conductivity sufficient to discharge amperes, as in commercial lightning arresters, or as in the gap G of Mr. Peek's tests will require considerably longer times.

This brings us now to the matter of spark gaps for measuring transient voltages. Since the current necessary to produce a luminous discharge is so small, a measuring spark gap does not need to develop the high degree of conductivity assumed above, and its time lag is much shorter, of the order of 10^{-8} seconds. This may be considered as instantaneous when the gap is used for measuring surges initiated by discharge gaps in the laboratory, or lightning strokes or insulator flashovers in the field, which require 10^{-6} sec. or more to develop their full conductivity.

Mr. Peek states that for most accurate work, no resistance should be used in series with measuring spark gap. I do not agree with him there in general as the leads to the spark gap necessarily have inductance, and as is well known, if a voltage is suddenly applied and maintained on an inductance in series with a condenser, the voltage on the condenser will rise to nearly twice the applied voltage. A somewhat similar question would be as to what is the best value of damping to put in the movement of an ordinary voltmeter to read accurately voltages which are suddenly applied and held on for only a brief time. If there is no damping at all, the movement will come most rapidly to the proper position, but it will not stop there. It will overshoot, and momentarily indicate too high values. The amount by which it overshoots will depend on the rate at which the applied voltage builds up. If the applied voltage builds up in a time small compared to the natural period of the movement, it will overshoot to twice the correct displacement. If the applied voltage builds up in a time large compared to the natural period of the movement, the overshooting will be negligible.

If too much damping is used, the movement will be sluggish, and will not reach the proper deflection during the time of application of the voltage.

To reach the proper deflection most rapidly and without overshooting, the movement should be critically damped.

Similarly, for a measuring spark gap it is best to use that value of series resistance which will critically damp the oscillations attendant upon charging the capacitance of the sphere gap through the inductance of the leads. When, as was most likely in Mr. Peek's circuits, the time of building up of the voltage is long compared to the natural period of the measuring sphere-gap oscillations, not much error will result in omitting this series resistance, but in other cases the error may be considerable. It is not unusual in the laboratory to find an undamped measuring gap indicating higher voltages than the gap initiating the impulse.

H. J. Ryan: In the high-voltage field, generally speaking, breakdowns of solid, liquid, or gaseous dielectrics are due to many factors, and often in very complicated relations. Exact knowledge of all circumstances is, therefore, of the highest importance. Systematic work under definite conditions is rapidly erecting a sufficiently complete understanding of high-voltage phenomena to assist greatly in placing causes of accidents of a high-voltage character in practise.

There is a duty imposed upon those who undertake to profit by these papers. They should remember in connection with Mr. Peek's paper what has been said therein regarding the conditions involving the time element. Where the time in action is so short, as was always the case in those studies, the results show that the discharges through the air require extraordinary voltages, having impulse ratios of about two, and values of 20 kilovolts, effective, per inch in air at common densities. On the other hand, the oscillator that delivers 120, 60,000-cycle wave trains per second produces discharges through air at ordinary densities with impulse ratios that begin at 1.5 for short distances, say *one foot*, and diminish with ever increasing rapidity to 0.67 at *eight feet*. In these circumstances the logarithm of the discharge distance is found to be proportional to the discharge voltage. The logarithms of numbers grow very slowly. The discharge lengths grow very rapidly, therefore, with voltages.

Finally, when we came to that type of discharge that is established through air with high voltages at continuous high frequencies, wherein some of the ionization that is established holds over from voltage crest to crest, the nature of this action is further developed and amplified. In comparatively short discharges the voltage per inch required to break down an air column may fall to the low value of 1.5 or 1 kilovolt. In these circumstances I am convinced that the value of voltage in relation to increase of discharge distances will continue to fall.

If one keeps up the action, increases the distance, follows it up with the requisite amount of voltage to accomplish breakdown, I am convinced that the value of voltage per inch of gap will fall below one kilovolt—a ratio of voltages from one extreme of circumstances to the other of 20 to 1, or more.

It is important, therefore, for those who study these papers and their discussions, to remember the conditions their authors carefully specified, under which they obtained their results.

D. D. Clarke: My own great interest in Mr. Peek's paper lies, perhaps, in the new tool that his work has given us in studying what happens on a transmission line and on distribution lines during lightning storms. Those of us who have been more or less responsible at times for keeping lines going, and the people of widely distributed towns in service during lightning weather, very greatly appreciate any move toward solving the peculiar problem of stopping the trouble.

There are several things in a lightning stroke as indicated on the line which are not entirely new to the operating man, but which might be divided into a few classes of phenomena. There is (1) the spit-over, which is not due to a direct stroke, but over which the power current may flow with destructive results.

There is (2), the direct stroke which may melt conductors and drop the lines.

And there is (3), the burning of poles by the power current which may drop the line.

Lines are classified in general as wood pole lines and metal supported lines. Outdoor substations are of course metal supported. The great interest in this paper, to me, comes particularly in the wood pole line construction. Occasionally on such work we find that the poles are split. In the three weeks preceding my attendance at this meeting, we had three distinct cases of such split poles. These are always accompanied by more or less splintering of the arm from the pin of one or more insulators, to the brace, showing that a very steep wave front has existed. Again, the poles in these three cases were distinctly split, but in no case dropping the line. In one of these cases not only one pole was split but four successive poles showed splinters.

The splitting of poles is dangerous to the operation of the line because it is liable to drop the line. It seems very probable that continued investigation with this new tool—the impulse generator—will lead to a solution of this problem and at the same time allow us to retain the very important added flashover value of the line as a whole due to the wood construction.

On a low-frequency oscillator we have demonstrated repeatedly that the wood, whether wet or dry, has a very distinct advantage in increasing flashover voltages of pole-line construction.

The flashover value of three or four feet of wood is so high as to make comparatively negligible the flashover value of the insulator itself. After the insulator flashover is over, the wood has sufficient resistance ordinarily to put out any ensuing arc.

Again, this paper strikes home to the operating man in protecting his substations. The substation is protected ordinarily by a lightning arrester from destructive insulation failure either due to flashover or puncture of transformer coils. The great problem with the operating engineer is to apply the lightning arrester so as to give it a chance to perform its function at all times.

The performance of lightning to date has been a very mysterious quantity. The man has quite a problem on his hands whose duty it is to investigate failure during a lightning storm in a substation which has been equipped with the most complete protective apparatus that modern science has put on the commercial market. He finds that the lightning arrester is set at a reasonable value, that the ground resistances are as low as they can be made on isolated construction—and yet it fails.

I feel that the experiments as indicated in Mr. Peek's paper have lent a way to solving to best advantage that problem.

D. M. Simons: I have been particularly interested in Dr. Whitehead's method of measurement, apart from the results which he has obtained. I do not think that the quadrant electrometer or electrostatic wattmeter has had sufficient recognition, and I would like to say a few words about this method of measuring dielectric losses.

A great many people seemed to have obtained an impression that the electrometer is a very fragile and delicate instrument. We have had one in service for 10 years without an accident and without even changing its suspension, and have found it a very valuable and rugged instrument.

Dr. Whitehead says that some of the errors in the electrometer such as that due to the charging current between the needle and the quadrant and others have not yet been worked out. We have done a lot of work on this subject and I hope that we can soon present some of this matter in definite equation form, which may help to add to the utility of the instrument.

We have been able to measure dielectric losses of an extremely low value, down to milliwatts, at high voltages and at very low power factors and to check our results very thoroughly. I merely want to add these remarks to emphasize what I believe is the very great importance and value of this method of measuring extremely low dielectric losses.

C. F. Harding: Mr. McEachron's paper will be recognized, I think, as confirmatory evidence of the nature of the corona discharge, particularly at the positive and negative electrodes respectively, which was presented some years ago by Mr. Peek and others. It might be well to emphasize the fact, however, that the two methods outlined in this paper provide opportunity for additional study of the variation of such corona throughout the cycle, with respect to time.

Also, it might be well to point out that in both of these cases the corona under investigation is simply that portion which affects the eye or the photographic film. Some recent investigations seem to indicate that corona formation may seriously affect insulation and produce the higher oxides of nitrogen, which in connection with moisture cause insulation to deteriorate, even though that corona does not affect the photographic plate or is not visual. That is particularly true in other portions of the spectrum than the ultra-violet, since the latter may be studied by means of quartz lenses.

Referring briefly to the next to the last paragraph on the second page of his paper, Mr. McEachron states that "At 15 kv. the discharge at 15 cycles (not reproduced here) was about as strong as that at 120 cycles, but the 30-cycle discharge showed no brush at all. At 8 kv. and 60 cycles there was no brush discharge recorded."

It may be that at certain voltages we have critical frequencies at which this corona effect takes place which may, at those frequencies, cause serious deterioration of insulation.

I wish to emphasize also the fact that there were a number of rather important developments brought out by Mr. McEachron in this work that will be published in a bulletin of the Engineering Experiment Station of Purdue University in the near future, which were not included in this paper.

R. B. Williamson: The factors influencing internal ionization, or internal corona, in built-up insulation as used on the coils of high-voltage generators are of great importance both to the designing engineer and also to the companies operating such generators. There has been a great deal of investigation and discussion during the past few years relating to the effect of temperature on various types of insulation and also the dielectric strength of insulations, but the questions of both internal and external corona have hardly received the attention that their importance warrants. A contribution such as the present one is therefore very timely and the results shown are of great interest and value.

For high-voltage machines, say 6600 volts and over, the thickness and composition of the insulating wall has as a rule

been determined for the most part by considerations of dielectric strength, and operating temperature. However, this question of corona in such high-voltage machines is in many instances really the most important determining factor in fixing both the thickness of the insulating wall and the character of the insulation. The tests described in this paper show the superiority of mica insulation, and experience extending over many years has also shown that mica resists the attacks of corona very much better than fibrous insulation. There are many cases, as in high-voltage moderate speed, waterwheel generators, where it is not necessary to use mica insulation so far as heat resisting qualities are concerned, because such machines, if provided with effective ventilation, will operate at temperatures well within the limits allowable for Class A (fabric) insulation. At the same time I believe that such high-voltage machines should be provided with mica insulation to take care of the corona action even though mica is not needed so far as thermal considerations are concerned.

It is interesting to note in these tests that evidences of corona appeared at an average potential gradient of about 16,000 volts per cm. or roughly 40 volts per mil. In an article published about ten years ago in England, by Fleming and Johnson on the chemical action of corona on coil insulation, numerous cases were cited to show that there was danger of such action in ordinary insulation if the volts per mil exceeded 35, and the authors recommended that the thickness of wall be made such that the potential gradient between conductor and ground be not over 35 volts per mil. It was recognized that dense hard mica insulation could be worked higher than this but the figure they arrived at checks up quite well with the potential gradient at which corona became evident in the present tests.

At the bottom of the seventeenth page, it is noted in the baking tests, that all the samples showed a swelling at the points where the electrodes were applied, and the internal ionization apparently was the most important factor in causing the insulation to bulge out. When the coil is placed in the slot this action is limited by the sides of the slot but in order to get the coils in place there must be some clearance and a slight spreading in service is almost certain. Besides, at the ventilating ducts the insulation is free to expand and it is at this point, unfortunately, that the effects of corona are frequently most in evidence because of the sharp corners at the edge of the ducts.. While, therefore, it is possible to make coils having a dense hard mica insulation, there is always the probability of some bulging under long continued operation. Moreover, longitudinal expansion and contraction of the copper will loosen the insulation and a certain amount of flexibility is highly desirable to allow the coil to adjust itself to varying temperature conditions and incidentally to facilitate winding.

Since, therefore, with insulation built up as on stator coils, it is more than likely that some voids will be formed under long continued operation even though these be small, we believe that such coils should be insulated with as high a percentage of mica as practicable even though the operating temperatures may not demand it, because mica is the best material we have available to withstand the corona. In addition, while a certain thickness of insulating wall may be sufficient, so far as dielectric strength is concerned, it may frequently be advisable to make it thicker than this, in order to reduce the potential gradient to a point where internal ionization will not be present to any injurious extent. For low-voltage machines the thickness of insulation necessary for mechanical reasons is usually such that the gradient as a matter of course, is so low that internal corona is not the determining factor, and for windings of this kind, a fabric insulation is satisfactory provided the machine is worked within the temperature limit allowable for Class A insulation.

D. E. Howes: Dr. Whitehead's results and conclusions should serve to give users of high-voltage generators confidence in the present structure of windings, and to point out to the manufacturer the importance of careful inspection and construction.

I would like simply to give the results of an investigation to show the potential gradient necessary to produce corona in air spaces of different thicknesses. That corona exists in small air spaces has been most conclusively shown by Dr. J. E. Shrader in a paper on "Corona in Air Spaces." If two dielectrics, 1 and 2, are in series with faces parallel to the electrodes, the gradient in one in terms of the total voltage applied is,

$$g_1 = \frac{E}{d_1\left(1 + \dfrac{d_2\,K_1}{d_1\,K_2}\right)}$$

where the d's and K's are respectively the thickness and specific inductive capacities of the two dielectrics and E the total voltage. In this manner the gradients necessary to produce corona were calculated from data obtained by the method described by Dr. Shrader. The results are shown in the accompanying curve, Fig. 1 where the gradient is plotted against thickness of air space for values of the latter from 0.004 cm. to 0.026 cm. For reference, the sparking potential in air between 1 cm. radius spheres is also shown. This indicates that, as would be expected, the potential gradient necessary to produce corona in small air gaps follows the same law as sparking potential, and does

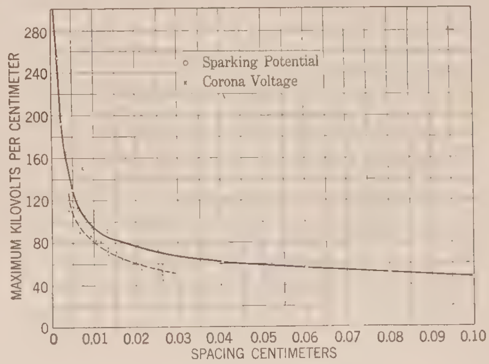

Fig. 1—Sparking Potential and Corona Voltage

not remain at the conventional value 30 kv./cm. The values fall slightly below the reference curve but this is to be expected when we consider the probable smoothness of the surface of separation.

We see that for very small separations the gradient required may be very high and in all probability the dielectric would rupture first. The curve emphasizes the conclusions of Dr. Whitehead's paper, that built up insulation must be well pressed together, and this is especially true where mica with a high specific inductive capacity is used. It would be desirable if a flexible impregnating compound could be used, but this probably is not feasible at the temperatures and conditions prevailing in an armature winding.

H. S. Warren: These very interesting tests which Mr. Peek has described have suggested to me the possibility of employing his equipment in a field somewhat outside its intended range. I refer to the efficacy of lightning rods for the protection of buildings against lightning.

The subject of protecting buildings—particularly farm property and buildings containing oils and explosives—has received considerable attention but has not been given the intensive scientific study which it deserves. In consequence, while the lightning rod is fairly well established in the opinion of those who actually provide such installations, there is room for legitimate doubt as to the necessity and sufficiency of the methods now commonly employed. This doubt is due to a

realization that the whole subject of protecting buildings against lightning rests on an inadequate foundation because of the lack of exact knowledge of the physical principles underlying lightning phenomena.

That this should be so is not surprising in view of the difficulties presented by a scientific investigation of the subject. To conduct in the field such an investigation, comprehensive enough to lead to conclusive results, is a most formidable undertaking.

I wish, therefore, to suggest for Mr. Peek's consideration the possibility of utilizing his apparatus to make laboratory tests in the endeavor to throw some light on the behavior of lightning discharges in the vicinity of buildings with and without different types of protective equipment.

In making this suggestion, I am not unmindful that lightning produced in the laboratory is small in comparison with the maximum voltages encountered in atmospheric electricity. Such tests could not presumably be conducted on a full-scale basis and any attempt to simulate by models practical conditions of exposure is fraught with uncertainties. Great care would have to be exercised in interpreting any results obtained in that way. However, the need of scientific data on the protection of buildings is so great that I am moved to raise the question. I hope Mr. Peek will take it up and see if something cannot be done which will be useful in that application.

F. W. Peek, Jr.: Messrs. Goodwin and Clarke are quite right in that wooden poles even when wet add materially to the line insulation for lightning voltages.

Referring to Mr. Peters' discussion, the table on page 625 gives the effect of various values of resistance in series with the sphere for a given wave. Obviously the effect will vary with the capacity of the sphere. The "instantaneous" voltage can only be measured when there is no series resistance or when it has a very moderate value. I have sometimes used a moderate value of resistance to suppress local oscillations. Generally this is not necessary. The duration of the transient is readily determined by measuring both the "instantaneous" voltage and the voltage with a high known resistance in series with the sphere. A small known inductance in series with the circuit shunted with a sphere gap offers a means of determining the wave front.

A lightning arrester with high impulse ratio or high series resistance in undesirable. The high series resistance has the effect of reducing the discharge capacity and also of increasing the impulse ratio.

The tests with the inductance coils show, I believe, that an inductance without shunt resistance may be dangerous.

Mr. Slepian's calculations are very interesting, I have made similar calculations. The difficulty in this, before the calculations are started certain assumptions must be made. While the calculations may be correct, there may be some doubt as to the assumptions upon which they are based. However, such work is often of great help in the final solution of a problem.

I naturally do not claim the accuracy for these measurements as that which could be obtained by leisurely reading the voltage with a meter in a d-c. circuit. Nevertheless I believe the accuracy is fair considering the difficulties.

Professor Ryan's word of caution is timely.

Dr. Jewett's observations add to the many peculiar phenomena caused by lightning voltages. I have observed that when voltages from the lightning generator are applied to a wooden post, it is blown apart violently. Examination of the two parts show a tiny hole lengthwise through the post where the wood has entirely disappeared. The wood has apparently been turned into a gas and tremendous pressures are thus produced. This effect is readily obtained on kiln dried wood.

Answering Mr. Warren's question, I am engaged at present in an investigation to try and determine the value of the lightning rod.

K. B. McEachron: There has been considerable comment among those who discussed Mr. Peek's paper concerning the explosive effect which appeared in the pieces of wood, poles and so forth. I don't wish to attempt any explanation, but I do want to call your attention to something which may help to explain it.

In J. J. Thompson's book on the "Conduction of Electricity Through Gases," which was published quite a good many years ago, there will be found a description of some experiments on the pressure developed in the electric spark. I remember being much surprised when I found that pressures as high as 600 atmospheres could be expected from the electric spark.

When it is remembered that in those experiments the spark was very small compared to the sparks with which Mr. Peek is working, or the sparks which we get in lightning discharge, it is clear that mechanical pressures may be produced which are sufficient to account, at least in part, for the stresses set up when the wood or other material is torn apart.

The reason why sparks produce oxides of nitro much better than the more gentle corona discharge, may be due to the explosive effect, combined with the difficulty of breaking up the nitrogen molecule.

Continued Discussions

RADIATION FROM TRANSMISSION LINES

(MANNEBACK), NEW YORK, N. Y., FEBRUARY 16, 1923

Continued from September JOURNAL, p. 981.

Chas. Manneback: I said (top second page of paper) "An electric disturbance, *i. e.*, a discontinuity of voltage or current, is always propagated along any line at the constant speed $v = 1 : \sqrt{L\,C}$." I added that "this is true whether there is resistance and leakance or not." Dr. Karapetoff is not sure that this is correct; it seems to him "that the velocity of propagation depends on the presence of resistance and leakance and is thereby reduced. "This difference in opinions is due, I believe, to the fact that we do not think of the *same* thing being propagated. The question raised is of great theoretical importance and deserves a careful examination.

Let us consider, for simplicity, a both sides indefinitely extending line. Let, at the time $t = 0$, the line be neutral everywhere, except over the short length $\Delta\, x$, at the point 0, origin of the coordinates ($x = 0$), where the voltage V has the uniform value $2\, V_0$. Let the current I at that moment be zero everywhere. Consider now that the line be left to itself, and an observer placed at a point whose distance is x (right or left) from the origin.

I maintain that nothing will happen at a point x before the time $t = x/v$ will have elapsed; but at the time t exactly, whether there is resistance and leakance or not present, a discontinuity of voltage and current will reach the point x. The voltage there will suddenly jump from zero to the value $V_0 \exp(-\,\rho\, t)$, where $\rho = 1/2\,(R/L + G/C)$. In other words, a disturbance, *i. e.*, a *discontinuity* of voltage, initially localized at the origin 0, will spread over all the line, in both directions, at the constant velocity $1 : \sqrt{L\,C}$. The discontinuity of voltage V_d is always accompanied by a discontinuity of current I_d, such that $V_d = \sqrt{L\,C}.I_d$. These two discontinuities together constitute the front of an electromagnetic wave along wires or the electromagnetic wavefront, and are the essential feature of any "electromagnetic disturbance" along wires. Without the presence of a discon-

tinuity, no sharp definition of a disturbance can be given. We thus say that the *front* of an electromagnetic wave along wires is always propagated at the constant velocity $1 : \sqrt{L\,C}$, whether there is resistance and leakance or not. However, the value of voltage and current at the wave-front or the height of the discontinuity is attenuated during the propagation if losses are present: there is an *attenuation* of the traveling wave. Similarly, the distribution of voltage and current behind the wave-front obey a more or less complicated law, depending on the presence of losses; there is a *distortion* of the traveling wave.

The voltage and the current are only features of the whole electromagnetic field surrounding the wires. The voltage at a given point of the line is the line-integral of the electric force taken from one wire to the other in a plane perpendicular to the wires. The current is the line-integral divided by $4\,\pi$ of the magnetic force around one wire in a plane perpendicular to the wires. These definitions assume that the electromagnetic field is a plane, which is true to a very close approximation provided the source of the disturbance is not too near. What was called the "classical" theory of electric lines rests upon that hypothesis. From this viewpoint, the notion of wave-front becomes more physical: it is the plane traveling parallel to the wires which separates the space into two parts, the one where an electromagnetic field is present, the other still untouched by the disturbance. Compare with the paragraph "Transient radiation from a transmission line," where the wave-front is a spherical surface, expanding with the velocity of light. The part of the sphere near the wires can very approximately be considered as plane.

A proof of the preceding can be given by going back to the fundamental properties of the partial differential equation

$$L\,C\,\frac{\partial^2 V}{\partial t^2} + (R\,C + L\,G)\,\frac{\partial V}{\partial t} + R\,G\,V = \frac{\partial^2 V}{\partial x^2}$$

that controls the propagation of any disturbance along a line. This equation is a linear partial differential equation of the second order with constant coefficients and two independent variables x and t. As L and C are positive, it is a so-called equation of the hyperbolic type, because it can be written

$$\frac{\partial^2 V}{\partial x^2} - 1/V^2 \, . \, \frac{\partial^2 V}{\partial t^2} = F\left(V, \frac{\partial V}{\partial x}, \frac{\partial V}{\partial t} \right)$$

where F stands for a linear function of the quantities in parenthesis and v a real positive constant equal in the present case to $1 : \sqrt{L\,C}$. The straight lines in the plane x, t parallel to $x \pm v\,t = 0$ are called the characteristics of the equation.

There is a general theorem that can be stated as follows: A. Sommerfeld—Die Randwertaufgaben in der Theorie der partiellen differential Gleichungen.—*Enzyklopadie der mathem. Wissenschaften* 11A 7c, p. 512): Given in the plane (x, t) the values of V and $\dfrac{\partial V}{\partial n}$ (normal derivative) along a portion of a curve $A\,B$, that is not intersected more than once by a characteristic line, there exists one and only one solution for V verifying the prescribed conditions along the curve $A\,B$; this solution is only defined inside the parallelogram made up of the characteristic lines starting from A and B.

From which it can be deduced (*loc. cit.* p. 533), that if for $t = 0$ the values of V and $\dfrac{\partial V}{\partial t}$ are zero everywhere[1] along the x-axis, except near the origin over the length $\Delta\,x$, V will be zero everywhere except inside the region delimited by $\Delta\,x$ and the characteristics diverging from the ends of $\Delta\,x$. There will thus be a discontinuity of the solution V in the space-time plane (x, t) along these characteristics. To interprete this, draw a parallel to the $+\,t$ axis from the point x on the x-axis. The values of V along that line will show us the time-succession of the voltage values at the fixed point x. We thus see that the voltage is zero until the parallel to the $+\,t$ axis reaches the characteristic, *i. e.*, until the time x/v has elapsed; then it suddenly jumps to a value that can only be known by formal integration of the partial differential equation of propagation. Drawing from the point t on the $+\,t$-axis a parallel to the x-axis, we have a picture of the distribution of the voltage along the line at the time t. We see that the disturbance, starting from the origin will have reached on both sides the point $x = v\,t$, but that further than x the line will be still neutral. A jump of voltage occurs at that point, which has just been reached by the front of the wave. This front is delimitated in the space-time plane (x, t) by the two characteristics diverging from the ends of $\Delta\,x$. As the ratio of the space coordinate x to the time coordinate t is constant along the characteristics (equals v or $-\,v$), the wave front starting from the origin reaches the point x on the line after a time $t = x/v$, *i. e.*, will be propagated at the constant velocity v.

We considered for simplicity a peculiar initial distribution of voltage over the line, any other would do, provided it is *discontinuous* at some place, which entails a disturbance originating there. Similar considerations can be developed if a voltage represented by an arbitrary function of time is impressed at a given point, say $x = 0$, over the line. This would amount to giving the initial values of V in the space-time plane along the t-axis instead of along the x-axis as before. The equation of propagation being the same for the voltage and current, all the preceding argument holds true for the current.

Thus, in general, whenever an electromagnetic disturbance, *i. e.*, a discontinuity in the initial value of either the voltage or the current, is produced at any point x on the line, at any time t (briefly at any space-time point on the line), the disturbance is spread all over the line by means of two abrupt wave-fronts traveling in opposite directions with the velocity $v = 1 : \sqrt{L\,C}$. The magnitude of the disturbance at the wave-front is attenuated with the time or distance according an exponential law previously stated. If the line is finite, reflection phenomena occur. At the time t after its initiation, the voltage disturbance will thus be composed of two "heads," *i. e.*, the two wave-fronts of magnitude $V_0 \exp\,(-\,\rho\,t)$, both at a distance $x = v\,t$ from the source, separated by a zone of diffuse character.

If the losses are rather small, as is the case for a transmission line, most of the initial energy of the disturbance will be equally congregated in the two heads, which means that the diffused disturbance between them is comparatively unimportant. In the theoretical case of a line without any loss, the initial disturbance of length $\Delta\,x$ and magnitude $2\,V_0$ will split into two heads, of same length $\Delta\,x$ and magnitude V_0, traveling in opposite directions at the velocity $v = 1 : \sqrt{L\,C}$ (*i. e.*, the same as when losses are present), but without suffering any attenuation nor distortion. An immediate proof is given by the well-known properties of the so-called "vibrating string equation."

$$\frac{\partial^2 V}{\partial x^2} - 1/v^2\,\frac{\partial^2 V}{\partial t^2} = 0$$

to which the general equation of propagation reduces in the present case. The solution is known to be the sum of two arbitrary functions, the one of $(x - v\,t)$, the other of $(x + v\,t)$, which involves propagation at the velocity v without attenuation nor distortion. Notice that the solution V is now zero everywhere in the space-time plane, except over the two strips made up of the two characteristics diverging from the two ends of the initial disturbance $\Delta\,x$. ($\Delta\,x$ need not be infinitely small).

1. Taking $\dfrac{\delta V}{\delta t} = 0$ is equivalent to taking the current $I = 0$.

If the losses are very high, as in a submarine cable, the heads of the disturbance, or its two wave-fronts are rapidly attenuated to such an extent that they become quite negligible compared to the "tail" or bulk of the diffused disturbance between them. Thus a fixed observer, far enough from the source, will not notice the passage of the wave-front at the velocity v, but will record a slow rise of potential, in fact following entirely the law of diffusion of heat in a bar. In the present case, as no sharp wave-front will have been noticed, the apparent velocity of propagation recorded will be undefinite, depending upon the resistance of the line and many other factors, including the sensitiveness of the measuring instrument. This explains the lack of agreement in the measurements of the velocity of propagation of the electric current "in" wires made by the early telegraph engineers.

Between those extreme cases there is a very important one, from a theoretical viewpoint, *viz.*, the case of a "distortionless" line, discovered by Heaviside, occurring when the relation $R/L = G/C$ holds between the line-constants. The distorting influence of the leakance then balances the distorting influence of the resistance. Both combine, however, in attenuating the wave front. No "tail" exists between the "heads;" the line is clear of disturbance between them. Two disturbances of length Δx (magnitude of Δx immaterial) are propagated in opposite directions, at the velocity v, being attenuated exponentially with the time and the distance, without suffering any distortion in their shape. An analytical proof for this is easily derived from the equation of propagation.

Heaviside, in his "Electrical Paper" (Section 44 to 47 of "Electromagnetic Induction and its Propagation" and Part 8 of "On the Self-Induction of Wires," both in the second volume) gives a very clear physical picture of these phenomena. He shows how a lumped resistance inserted in a perfect line, *i. e.*, without losses, produces a partial reflection of an impinging disturbance, and how a shunted leak produces a reflection of an opposite character, so that both may cancel each other, as far as reflection is concerned. But it is precisely the sum of an infiite number of such reflections due to an infinity of very small lumped resistances and leaks, finally approximating the real line with distributed resistance and leakance, that produces the transfer of energy from the head (wave-front) into the tail of the traveling disturbance which means distortion of the wave. On the other hand, both lumped resistance and leakance produce an attenuation of the direct wave, because the heat generated in them diminishes the amount of energy carried by the traveling wave. This illustration alone, however, is not sufficient to give complete information concerning the velocity of propagation of the wave front.

It may be remarked in passing that the theory of electromagnetic waves "along" wires (rather than "in" wires) is best deduced from the theory of free electromagnetic waves in a dielectric, there being no essential difference whatsoever between a "free" electromagnetic wave and a wave "guided" along wires. The difference merely arises from the penetration of the electromagnetic field into the wires. This way of proceeding, from the free to the guided wave, was first used by Heaviside (*Electromagnetric Theory*, vol. 1, sect. 199 to 203 and 206), later by M. Abraham in his "Theorie der Elektrizitat" (end first vol.). It is the most logical, as it gives a link between Maxwell's theory of free waves in the dielectric, expressed in terms of electric and magnetic forces, and the older "classical" theory of waves (guided) along wires, expressed in terms of voltage and current (which are but line-integrals or "circulations" of the electric and magnetic forces) and in terms of the so-called line constants, resistance, leakance, capacitance and inductance per unit length, (the two latter being surface-integrals or "fluxes" of the electric and magnetic forces). At the same time the limitations of the classical theory and of the notion of line constants is clearly thrown into light. (See above references; also M. Abraham, Die Energie elektrischer Drahtwellen.—*Annalen der Physik*, vol. 23, p. 44, 1907).

The preceding considerations, however, seem to be in conflict with the well-known result given by the hyperbolic theory, which is often stated as follows "the velocity of propagation of an electromagnetic wave along wires is a function of the frequency and of the four constants of the line: resistance, leakance, inductance and capacitance per unit length." The statement would be more correct in saying "the velocity of propagation of the *phase of a sinusoidal harmonic wave* along wires is a function of the frequency and the line constants. For the hyperbolic theory applies to steady state sinusoidal alternating currents *only*, that is to a line over which a sinusoidal harmonic e. m. f. is impressed. Thus the state of things is assumed to be periodic everwhere with respect to the time, to have been always so, and to remain so indefinitely. Hence, a sudden transient phenomenon cannot be considered in that theory, especially no discontinuity in the values of the voltage or the current. Therefore an electromagnetic disturbance, *i. e.*, as we defined it, a *discontinuity* of voltage and current is entirely out of the realm of the hyperbolic theory.[2] There can thus be no objection from the standpoint of this theory against the constancy of the velocity of propagation of a *wave-front*, whatever the amount of resistance and leakance present in the line may be. Moreover, the idea of the velocity of propagation of the phase of a sinusoidal electromagnetic wave does not correspond to anything physical. It merely represents the velocity at which an observer would see a point, say of zero voltage or zero current, moving along the line. That velocity bears no connection at all to the velocity of the wave-front of a disturbance, a subject which was considered previously. The velocity of a wave-front is always that of light in the surrounding dielectric where it travels; the velocity of the *phase* of a sinusoidal wave can be either less or greater than the velocity of light. (M. Abraham, Uber die Phase Hertzscher Schwingungen, *Annalen der Physik*, vol. 67, p. 834, 1901. Shows that the velocity of propagation of the phase of the magnetic force near an Hertz's oscillator can reach any value *above* the velocity of light. (Consider a steady source of sinusoidal harmonic voltage applied to an infinitely long line ever since an infinitely long time. Suppose first that the curve of voltage, instead of being a pure sinusoide is composed of a steady succession of a great number of small steps approximating very nearly to a sinusoide. There will be thus a great number of small voltage discontinuities, *i. e.*, wave-fronts, following each other over the line at the constant velocity $1 : \sqrt{L\,C}$, attenuated as they travel, and leaving behind them a diffused "tail," as we have already seen. The combination of all these small waves gives a resulting distribution of voltage over the line, approximating the better the hyperbolic distribution the smaller the steps of the applied voltage. We thus see that when at some "space-time" point of the line the voltage is, say zero, it only means that the multitude of elementary waves which we have considered cancel each other, at that space-time. Hence, the velocity at which that point of zero voltage travels along the line (the slope of its space-time line) bears no relation at all to the velocity of propagation of a wave-front, which only has a physical meaning. The so-called velocity of propagation of the phase is introduced in the hyperbolic theory as quotient of λ/T, "wave length" by period of the sine wave considered. These two quantities have a physical meaning. The "wave length" is twice the distance between two successive nodes of the damped *stationary* wave that exists in a finite electric line when it subsides freely, under no external impressed

2. Building up, however, Fourier series or integrals by means of an *infinity* of elementary hyperbolic solutions of *different* frequencies, it would be possible to introduce a discontinuity. But this would only be a long means of solving the fundamental partial differential equation of propagation.

force. In other words, λ is the wave length of a *normal* system of vibration of the line.

Answering the second question of Dr. Karapetoff it may be remarked that equation (**9**) of paper

$$S = \frac{c}{4\pi} \int E\, H\, d\, \Sigma$$

expresses in the present case the well-known Poynting's theorem of the flow of energy in the electromagnetic field. (See Pierce's "Electric Oscillations and Electric Waves," p. 374). The equation is absolutely general, holding for any kind of electromagnetic field. Pierce's formula of the stationary (*i. e.*, steady state a. c.) radiation of an antenna given in the last chapter of his book is only an application of the above Poynting's formula. The complication of the result arises from the fact that Pierce considers a flat-top antenna, being composed of a vertical part and an horizontal part. We considered a different case: the stationary radiation of two straight parallel wires (antenna). Our result, which is given by formula (**10**) in the paper, is but an application of Poynting's theorem. An intermediate case, where the result is a little more complicated than ours, is that obtained by M. Abraham for the stationary radiation of a single straight wire (antenna). (See Funken-telegraphie und Elektrodynamik, *Physikalische Zeitschrift*, p. 239, 1901). In fact, it is Abraham's method that was used in the paper.

Regarding the third question raised by Dr. Karapetoff, it must be remembered that if the principle of superposition may be applied to the electromagnetic field, *i. e.*, the electric and magnetic forces of two superposed fields may respectively be added to give the resultant force, it is because the partial differential equation of propagation, of which they are particular solutions, is linear. Such is not the case with the energy which is a quadratic function of the electric and magnetic forces. The procedure that was used to calculate the stationary radiation of a transmission line is really not different from that used to calculate the transient radiation; in both cases the electric and magnetic forces at great distances due to each wire were added together (superposed), (see equation 5, 6 and 7), and from the resulting field the radiated energy was deduced.

Dr. Slepian's point of view is very original. It is a well-known result of the theory of electrons (see H. A. Lorentz, Theory of Electrons) that a uniformly moving charge carries with itself its electromagnetic field, without radiating any energy: there is mere convection of the energy. But as soon as the velocity of the charge varies, being either increased or decreased, a variable electromagnetic field is set up originating at the charge and propagating from it with the velocity of light, thus radiating energy away from the moving centre. The radiation of energy is proportional to the square of the variation of velocity per unit of time (acceleration) of the electron, provided the velocity is not too near that of light. Hence, no charge, initially at rest, can reach the state of uniform motion without radiating at least some energy, which however, may be quite negligible compared to the convected energy.

DEVELOPMENT OF THE LARGE ELECTRIC MELTING FURNACE (HODSON),

PITTSBURGH, PA., APRIL 25, 1923

(Continued from November JOURNAL, page 1202.)

Frank Hodson: I am afraid the discussion on my paper describing in a preliminary way the large eight-electrode Greaves-Etchells furnace, now nearing completion, has resulted only in what might be termed competitive criticism, yet some of the statements are so misleading that they should not be allowed to pass unchallenged.

The fact that this particular furnace—which has over three times the kv-a. rating of any previous furnace built, and is capable of holding three times as much metal as any previous furnace, is original and marks a great advance in the art of electric furnace melting, seems to entirely escape the attention of our critics.

With regard to Mr. W. E. Moore's discussion, the development of better refractories would undoubtedly tend to prolong the life of all furnaces and experiments are now being made on electrically fused magnesite and dolomite with promise of considerable success, but correct heat distribution and electrical design offer more difficulties in large furnaces than choice of refractories.

With regard to size of electrode; my paper rightly points out the limitations in size of any three-top electrode furnace—because such electrodes are definitely limited to a certain kilowatt input that can be economically conveyed to the charge. Also there is a limit to the amount of heat energy which an electrode can efficiently transfer to a bath of molten metal without local superheating. Mr. Moore does not believe the size of three-electrode arc furnace is limited to 30 or 40 tons and he further states that electrodes 32 in. in diameter are in quite successful operation—presumably on the type of furnace under discussion, for hot or cold melting of 60-ton charges.

I have the written authority of each manufacturer of carbon electrodes that the largest size of electrode known, made, or used in the steel trade is 24 in. diameter.

Regarding the self baking type or "Soderberg" electrode, Mr. Moore's statement as to the possibility of using larger Soderberg electrodes is merely a repetition of my own suggestion. Unfortunately the larger an electrode becomes in cross-section the less its current-carrying capacity per square inch and consequently the greater the electrode consumption per kilowatt-hour of work done; it is not as Mr. Moore assumes, just a case of surface exposed to oxidization, although as a matter of fact, even if carbon electrodes were available of double present size, the actual area of electrode in our eight-electrode furnace is considerably less than would have to be used on a three- or four-electrode furnace having to introduce the same amount of current. A three-electrode furnace could not have introduced economically one third of the power required in this furnace and was therefore quite out of the question. The remarks above enumerated as to limit of energy transmission per electrode effectively dispose of this single electrode furnace as an ideally large furnace.

Relative to Mr. Moore's remarks on conductive linings. The lining itself is exactly the same as would be used on any other basic furnace performing the same operation. Break outs are not characteristic of heart-conducting furnaces more than any other, and good steel making demands a uniform steel without the chance of metal freezing on the hearth.

On large three-top electrode furnaces, this has been one of the chief difficulties. In spite of that I can give numerous instances where three-top electrode furnaces "cut through" and a couple of cases where such furnaces did actually topple over. Such a case as that related by Mr. Moore has never happened to a Greaves-Etchells furnace. There have been breakouts as on any other furnace, but no toppling. After ten years experience of furnace linings, I am convinced that with intelligent use there is no more deterioration on a Greaves-Etchells basic lining than on any other basic lining. The conduction of current causes it to set more firmly and to become more homogeneous. Scores of furnaces could be quoted if necessary that have done thousands of heats on one bottom for periods of over three years. Any basic hearth will deteriorate by standing unused.

The furnace described is designed to melt and refine real steel but if the user should at any time wish either to use it as an acid furnace or to put power only through the top electrodes, the Greaves-Etchells system permits this to be done, and in addition gives a balanced load on the primary and independent arcing of

each electrode. So that at the worst, you have better electrode control, balanced load, better distribution of heat and bottom heat available when wanted.

The point regarding multiplicity of electrodes appears very weak. More electrodes mean division of heat and more even heating of charge and of the furnace walls. A furnace of this size, if it were possible with three electrodes, which it is not, would burn down any refractories ever made.

Central hot spots would leave decidedly cold spots on large portions of the bath and the formation of refining carbide slag takes place under the arcs not in hot spots.

Mr. Moore's remarks regarding the current-carrying capacity of furnace bottoms entirely overlook the fact that the furnace may operate with no current through bottom. Assuming the bottom connection is switched in the lining on the Greaves-Etchells after having been properly installed and burnt it is conductive when cold and does not alter its resistance within very wide limits on heating.

The small variation which does take place does not lower the power input as much as 10 per cent. The furnace never starts as a single-phase furnace and Mr. Moore's criticism of "hot spots" may be characteristic of some, but not of the "Greaves-Etchells" furnace expertly installed.

The question of a "false bottom" is a matter of simple common sense precaution. Break-outs of molten steel in such bulk may happen through any lining, basic conducting, or non-conducting, and it would be foolish to neglect obvious precautions to limit damage done by such accidents.

Regarding the question of balanced load, no claim is made that the electrical circuits in the furnace are symmetrical—although it can very easily be proved that they are balanced, which is the thing that really matters. The balance obtained on the primary system of the transformer is what most concerns the power station. Moreover it is impossible even with only one electrode arcing to cut load off any one phase. Sufficient data are available from furnaces operating to show that a Greaves-Etchells furnace never overloads one primary supply phase while at the same time throwing the load off another. Whatever fluctuations take place inside the furnace—and these are less violent than with any three-electrode furnace—these are damped down by the Greaves-Etchells system and divided, not equally, but proportionately, over the three primary phases. This surely constitutes a boon to users who are on a maximum demand scale as it materially lifts the load factor.

Regarding shape of furnace there is a limit to the size of circular furnace on account of the doming of the roof—this exposes too great a length of electrode and also causes waste of heat. Mr. Moore's remarks are perhaps applicable to a three-electrode circular furnace but do not have much real bearing on the furnace described.

Mr. F. W. Brooks raises rather an interesting point as to whether comparison can only be made on American practise in making basic electric steel. The method of applying heat and power to electric furnaces and the method of steel making in such furnaces are identical the world over. Exactly the same type of furnace as that described in my article is being used with great success in Sweden and in England on melting cold charges up to 25 tons capacity. If this can be done in Europe it can undoubtedly be done here. A number of Greaves-Etchells furnaces in this country are operating on cold charges up to 15 tons of metal, not 6 tons, as mentioned. The three-electrode furnace of which Mr. Brooks states he knows several operating on 50-ton charges can only be the two 30- to 40-ton hot metal furnaces at Charlestown. W. Va. I have already dealt with the capacity of these.

The real test of a furnace is not in treating liquid metal, but its behavior on melting and refining combined. A 3000 kv-a. furnace such as those installed at Charleston may take 40 tons of hot metal but it is only comparable to a 10 to 12-ton furnace of the same transformer capacity for cold melting. Regarding the change on the large Greaves-Etchells furnace from top and bottom heating to top electrode only by movement of switch, this is literally accomplished by change of switch as a part of cutting off current with control switch. The actual reversal can be done by one other switch. The electrical apparatus of the Greaves-Etchells system and of this switching, is no more complicated than that of any other furnace although, diagrammatically, it may appear so.

Two spare electrodes of the dissimilar characteristics are necessary and in a large furnace such as this with 8 electrodes, employing 12 windings, two spare electrodes are insignificant. Apart from this, the periods over which spare electrodes should be necessary on a well built equipment, would form a very small percentage of the total installation cost of the furnace. The design of the furnace might have employed six electrodes and accomplished all that has been carried out with the eight electrodes, as far as arranging current distribution for top electrodes only, but for reasons of heat distribution over such a large mass of metal, it was thought better to employ eight electrodes.

With regard to the actual amount of bottom heating that can be obtained some actual tests carried out on a 10-ton Greaves-Etchells furnace showed that the actual energy put into the metal from the bottom connection was found to be 156 kw. out of a total of 1350. This is just the essential feature that makes the difference between fluid homogeneous steel and pasty mess.

The question of acid lining usually does not determine the merits of a furnace and in this case chemical refining on a basic lining was necessary to the process. Mr. Brooke apparently overlooks the fact that if top electrodes only were used, the nature of the lining whether acid or basic, is immaterial. In regard to heat conduction, since the materials used in this particular lining are exactly the same as those employed in ordinary basic furnaces using top electrodes only, their heat conductivity must be the same. As a matter of fact very many top electrode furnaces have electrically-conducting bottoms but do not make use of them as such. If there were an increase in heat dissipation this would be reflected on power consumption and sufficient evidence exists to show that the Greaves-Etchells type of furnace in similar operation are even more economical in power than top electrode furnaces.

In regard to the balanced load, the three-top-electrode furnace is a pre-supposed mathematically correct balance on paper, but who ever saw it do so for 60 seconds continuously in actual practise? To do so means that each arc was steadily and invariably loaded, a condition which never occurs in any arc furnace. In the three-electrode furnace, the fluctuation of each arc is faithfully reflected on its particular phase of primary supply, but in the Greaves-Etchells system the fluctuations are divided over all three phases of primary. A glance at any Greaves-Etchells furnace curve load and compared with any three-electrode furnace, would prove the correctness of this statement.

Mr. E. B. Dawson is wrong in his assumption that the Greaves-Etchells furnace requires additional transformers when operating in an acid bottom. This is not the case. I sincerely hope that Mr. J. A. Seede and Mr. E. T. Moore are correct in their views in regard to the development of large induction furnaces, but I am very much afraid that with large induction furnaces we should very quickly be up against objections from the power companies and also run into considerable trouble with refractories. The cost is also prohibitive. The writer can quite understand that Mr. Moore and Mr. Brooke and others are confused as to what exactly is happening in the secondary phase balance and power absorption of the hearth of a Greaves-Etchells furnace. The real proof of this furnace is in the heating of the metal and the efficient way in which it does it.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

LIGHTING DESIGNED FOR THE STANDARD BOWLING ALLEY

A proper lighting system for bowling alleys must accomplish two fundamental and clearly defined objects. The first is to produce a cheerful, bright, and comfortable atmosphere which will serve to attract customers to the alleys. In most cases, bowling alleys are located in basement or ground floor areas and attractive lighting is essential if the very natural disinclination to go below ground is to be entirely overcome.

The second object to be accomplished is to light the alleys and the pins in a way that will provide the best possible visual conditions for the bowler and at the same time avoid any unnecessary discomfort to the pin boy.

Very commonly in the past, bowling alleys have been lighted too dimly both as regards the seating spaces and the alleys. Sometimes no special provision has been made for lighting the pins to an extra brightness, and in other cases a lamp with or without some form of shade has been dropped down near the head pin. This expedient has increased the quantity of light on the pins but has often resulted in serious glare in the eyes of the pin boy, who is therefore tempted to shield his eyes by hanging pieces of newspaper over the lamp. Such practise, of course, not only reduces the illumination but creates an unfavorable appearance.

Fig. 1

The low-mounted lamp just above the head pin also has the disadvantage of casting its brightest light in a spot on the alley instead of uniformly on the faces of the pins.

The accompanying photograph shows the design developed for alleys of standard construction to provide good illumination and to avoid, in so far as possible, the faults of prevailing types of lighting.

Over the center of each alley is installed a row of seven 100-watt lamps of the frosted type in angle metal reflectors. These are mounted at a height of 7½ ft. above the alley and provide evenly distributed illumination of about 12 foot-candles upon the alley surface. The angle reflectors prevent the reflections or back-glare which cannot be avoided where ordinary direct lighting reflectors are used over the alleys.

Then, in order to make it easy to concentrate attention upon the pins, a beam of light giving an illumination of about 25 foot-candles is directed upon the pins from a small floodlighting projector of standard type equipped with a 150-watt, gas-filled lamp. A projector is mounted over each alley at a point 19 ft. ahead of the pin at a height of 7½ feet above the alley. Each is equipped with a cut-out mask of a form to cut off stray light to shield the eyes of the pin boy from possible glare.

With this combination of angle reflectors for the alleys and floodlights for the pins, there is ample illumination without sharp contrast, and the pins upon which the bowler's attention needs to be concentrated stand out sharply under the high intensity directed upon them.

The experience of bowlers who have tried these alleys in comparison with alleys lighted with less carefully planned sytems, is that their enjoyment of the game is appreciably increased and they feel that they are able to bowl with a higher degree of accuracy.

Over the spectators' seats, enclosing units of diffusing glass are installed on a spacing of approximately 10 ft., and provide 5 foot-candles of well diffused illumination. This is sufficient for keeping scores and provides a comfortably bright atmosphere.

The cost of better lighting for bowling alleys is relatively slight as compared with the benefits, and many owners of such establishments would profit greatly in increased number of customers by bringing their lighting up to date.

ELECTRIC SIGN LAMP DEVELOPMENT

It has often been remarked that the progress of electrical advertising has been dependent on the development of electric lamps. While this is obviously unfair to all of the other elements, which in long, painstaking experimentation have been evolved, it is in some degree nevertheless true; although, of course, the reverse is also true as well, lamps have been developed to meet the growing needs of electrical advertising.

The earliest electrical signs, perforce, had to use the earliest electric lamps, the carbon filament lamps, and even back in trade papers of the early '90's, we find reference to the wonderful developments of that day in electric sign lamps.

One of the most significant steps ever taken, however, in the slow evolution of electric sign lamps took place as recently as two years ago. Gas-filled lamps had, at that time, been available for a number of years. Daylight lamps were comparatively new, and there had been no wide-spread realization of the tremendous

value of these lamps for obtaining varying degrees of brightness. Few lamps with the concentrated form of filament had been used for this purpose. Sign designers who, thinking that a big sign needed big lamps, substituted 25-watt lamps for the then standard 5 and 10-watt lamps, were disappointed. It was difficult to tell the difference in the finished sign. The 25-watt lamps having also the long open filament, looked very much like the 10-watt lamps in the competing sign and the 5-watt lamps looked different only because they were made for low voltage and the filament shape was somewhat different. The color and brightness of all were approximately the same.

With the application, which began two years or so ago of 50, 75, and even 100 and 150-watt lamps in exposed lamp signs came the rapidly growing appreciation of the very great value of brightness. A display was not merely bright; it was not merely an outline in fire. It was for the first time made very bright or less so to suit the location and the desires of the advertiser.

Brightness was Overdone

For a while this idea of brightness was carried to an extreme. Many of the other tools which in the hands

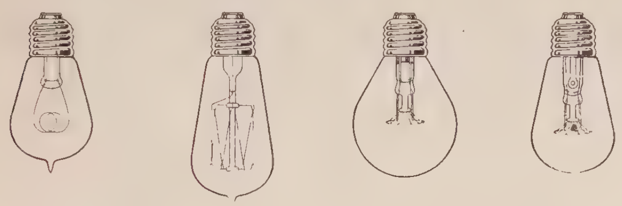

Fig. 1 Fig. 2 Fig. 3 Fig. 4

Fig. 1—Earliest Signs used Carbon Filament Lamps

Fig. 2—The Side Candle Power was a Drawback in Open-Filament Lamps

Fig. 3—The Mill-Type Lamp affords Brightness and Ruggedness

Fig. 4—Modern Coil Filament Low-Wattage Sign Lamp

of the resourceful designer had always been successful, were partially forgotten. For the moment, only brightness counted, until there were high wattage lamp signs in every town and in the most out-of-way places; many times the brightness was so overdone that the advantage of greater attracting power was completely offset by loss in legibility.

But like all worth-while innovations, the proper use of brightness in electrical advertising after somewhat over-shooting the mark in some instances, is now settling down to a more rational engineering basis. Proper brightness is recognized as a function of the location and the circulation and is being chosen accordingly. Designers have learned how to use brightness and still retain legibility. The wheel of progress never stops, and out of the wave of brightness, a new lamp development is now in the act of birth. Experience with the Mazada C lamp brought out the fact that the concentrated coil-filament was not only apparently more bright because it directed the light more strongly out through the tip toward the observer, but it was also considerably more rugged. Anyone who has used the comparatively new P-19 mill-type lamps will substantiate this. The wire, which is wound in a fine coil, gives and springs instead of bending on the supports. So the trade was benefitted in two ways. It got brightness and it got ruggedness. Sign lamps often have to submit to very rough handling in their journey in a sign man's hip pocket to the top of an 80-foot steel structure in a 40-mile gale at night, and the new lamps were found to stand up better than the old under this treatment.

Coil Filament Becomes Standard

The advantage was great enough so that the same construction is now to be used for all sign lamps down to and including the 5-watt size. The high side-candle power from the open filament construction, while an advantage in signs of certain types, is relatively less desirable for signs in general than the combination of greater brightness and greater ruggedness. As of September 1, therefore, the coil-filament construction becomes standard and replaces the old familiar so-called barrel type of filament.

This is not all. The use of this concentrated form of filament makes possible still another improvement in the 5, 10 and 15-watt lamps. The filament occupies so much less space that it is possible to make the bulb considerably shorter. All sign men will hail this change as a boon, especially because the tipless construction will also be used. More lamps in the same space for storage and cartage, less weight and less bulk to haul to the top of the big signs, smaller and neater appearance in low-hanging signs, shorter and more rugged supports for color hoods, shallower troughs, more room in small enclosed lamp signs, these are some of the reasons why this change will be welcomed.

The change should also hasten an improvement in design method which will greatly improve the appearance in another way of exposed lamp signs as they are built in the future. There should be a tendency to use the smaller lamps more closely spaced, reducing the number of badly spotted effects which are sometimes found at the present time.

SURVEYING THE ELECTRICAL APPLIANCE FIELD

Figures from a survey made by *Home Equipment Magazine* relative to the number of electrical appliances in use in each 1000 average wired homes show the following: 360 have vacuum cleaners, 112 have toasters, 295 have clothes washers, 48 have electric sewing machines, 11 have dishwashers, 360 have fans, 6 have electric refrigerators, 125 have bell-ringing transformers, 720 have electric irons, 16 have electric ranges.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

Opportunity for Visiting Engineers

An effort is being made to procure for JOURNAL publication advance notices of Section monthly meetings. Throughout the greater part of the year each Section of the Institute holds a monthly meeting, usually in a large industrial center, and in view of the fact that at all times many members of the Institute are traveling on business it is probable that engineers away from home would be glad of opportunities to attend Section meetings when the dates coincide with their visits in these centers.

Engineers away from home always are welcome guests at Section meetings. The Section officers are particularly eager to have visiting engineers attend these regular meetings, and there is much to be gained both from the Institute and the personal viewpoints when Institute members avail themselves of every opportunity to get-together at meetings where engineering subjects are discussed.

Section Secretaries are invited to send to the editor notices of meetings as far in advance as possible.

Chairman McNicol Visits Sections

Donald McNicol, Chairman of the Publication Committee, in October visited officers of the Chicago, Akron and Milwaukee Sections. In Milwaukee, a special meeting of officers of the section was held for the purpose of discussing various subjects of importance to the Publication Committee and to the section. Present at this meeting were: R. B. Williamson, S. H. Mortenson, Fraser Jeffrey, W. H. Powell, H. W. Cheney and A. K. Birch.

Midwinter Convention Plans

MEETING IN PHILADELPHIA, WEEK OF FEBRUARY 4, PROMISES RECORD ATTENDANCE AND INTEREST

The Midwinter Convention will be held in Philadelphia February 4-8 and the program has been sufficiently advanced as to indicate a very big and interesting convention. Several features of special valne will add to the interest aroused by the presentation of about forty technical papers which will discuss all phases of the electrical art.

CELEBRATION OF 40TH ANNIVERSARY

As the convention marks the 40th anniversary of the Institute, plans have been made to celebrate the occasion in a fitting mánner by having several of the original organizers speak and in addition a speaker to pay tribute to the accomplishments of the Institute. This meeting will be held on the evening of February 4th. Messrs. T. C. Martin, Elmer Sperry, Elihu Thomson and J. J. Carty have accepted invitations to speak.

RAILWAY SESSIONS

A departure in convention practise will occur at the convention in that an allied industry will have the opportunity to hold a big meeting under the auspices of the Institute. The transportation industry has been invited to present the engineering and economic aspects of the national transportation problem. At an afternoon meeting on February 5th at the Bellevue-Stratford, railroad presidents and operating officials will speak on the engineering of modern transportation. They will give the performance now given by steam transportation including train tonnages, locomotive performance, train movements, terminal movements, train speeds and acceleration rates, and in addition will speak of the future requirements of transportation.

At an evening meeting in the Metropolitan Opera House, national aspects of transportation will be treated by national authorities. Acceptances have been received from President Maher of the Norfolk and Western, President Budd of the Great Northern Railway, President Markham of the Illinois Central and Vice-President Buckland of the New York, New Haven and Hartford. Also prospects are bright for having Secretary Hoover and President Smith of the New York Central as speakers for the evening program. Plans are under way to broadcast the evening program by wire and radio from Chicago, Boston, New York and Philadelphia through the cooperation of the Bell system officials. The railroad officials are heartily cooperating in making a program which will produce the greatest meeting on transportation ever staged in this country.

DEDICATION OF NEW MOORE SCHOOL

The New Moore School of Electrical Engineering at the University of Pennsylvania will be dedicated by the Institute on the afternoon of February 6th and the local committee in Philadelphia in cooperation with the University authorities are arranging plans which will result in an unusually interesting and profitable visit as guests of the University of Pennsylvania.

ENTERTAINMENT

On Wednesday evening an informal smoker, dance and entertainment will be provided and on Thursday evening the annual dinner dance will be held at the Bellevue Stratford Hotel.

The Lehigh Valley Section has planned a very interesting afternoon and evening for Friday the 8th. The immense plant of the Bethlehem Steel Company will be visited in the afternoon and in the evening the visitors will be guests at an entertainment and meeting given by the Lehigh Valley Section.

TECHNICAL PROGRAM

Papers for the convention are numerous and interesting and treat of many phases of electrical engineering. A particularly notable group of papers will deal with superpower transmission and very greatly advances the knowledge of stability and performance of these systems. In research and electrophysics,

papers will be presented dealing with insulation, ionization, magnetism and dielectrics. Three papers dealing with modern elevator control and design will feature one of the meetings and several other good papers will deal with other industrial aspects of electrical engineering.

New kilovolt-ampere meters and a novel high-resistance voltmeter will be discussed at one of the sessions and several very interesting and valuable papers on radio, telephony and telegraphy have been prepared. Electrical machinery papers have been lacking at recent Institute meetings but for the Midwinter convention several papers have been received that will bring out much profitable discussion.

Headquarters will be at the Bellevue-Stratford Hotel in Philadelphia and the local convention committee is using every effort to make the convention a great success.

Program for Midwinter Convention

Monday, February 4

Morning

Registration and committee meetings

Afternoon

Technical Session

Economics and Limitations of the Super Transmission System, by Percy H. Thomas, Consulting Engineer, New York, N. Y.

Some Theoretical Considerations of Power Transmission, by C. L. Fortescue and C. F. Wagner, both of the Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Power Transmission, by F. C. Hanker, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Power Limitations of Transmission Systems, by R. D. Evans and H. K. Sels, both of the Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Experimental Analysis of the Stability and Power Limitations of Transmission Systems, by R. D. Evans, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa., and R. C. Bergvall.

Evening

Celebration of the 40th Anniversary of the Institute. Speakers: T. Commerford Martin, Elihu Thomson, Elmer Sperry and J. J. Carty.

Tuesday, February 5

Morning—Technical Session

Gaseous Ionization in Built-Up Insulation-II, by J. B. Whitehead, Dean, School of Engineering, Johns Hopkins University, Baltimore, Md.

Overdamped Condenser Oscillations, by Charles P. Steinmetz,* Chief Consulting Engineer, General Electric Co., Schenectady, N. Y.

Thermionic Rectifiers and Inverters, by D. C. Prince, General Electric Company, Schenectady, N. Y.

Thermionic Tubes, by E. F. W. Alexanderson, General Electric Co., Schenectady, N. Y.

Free Convection of Heat in Gases and Liquids-II, by C. W. Rice, General Electric Company, Schenectady, N. Y.

The Magnetic Properties of the Ternary System Fe-Si-C, by T. D. Yensen, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Alkali Vapor Detector Tubes, by H. A. Brown and C. T. Knipp, both of the University of Illinois, Urbana, Ill.

Afternoon and Evening

Operating Aspects of Railroad Transportation and Transportation Meeting at Metropolitan Opera House, addresses by Ralph Budd, President, Great Northern Railway Co.; N. D. Maher, President, Norfolk and Western Railway; C. H. Markham, President, Illinois Central Railroad; Edw. G. Buckland, Vice-President, N. Y., N. H. & H. R. R.; L. G. Coleman, Asst. General Manager, Boston & Maine Ry. (Other speakers to be announced later.)

*Deceased October 26, 1923.

Wednesday, February 6

Morning—Technical Session (A)

Transient Performance of Electric Elevators, by David Lindquist, Otis Elevator Co., New York, N. Y., and E. W. Yearsley, Electrical Engineer, Brooklyn, N. Y.

Variable Voltage Control Systems as Applied to Elevators, by E. M. Bouton, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

A Novel Alternating-Current Voltmeter, by L. T. Wilson, American Telephone & Telegraph Co., New York, N. Y.

Oscillographic Study of Voltage and Current in Permeameter Circuit, by W. B. Kouwenhoven, Dept. of Electrical Engineering, Johns Hopkins University, Baltimore, Md., and T. L. Berry Jr.

Power Plant Auxiliaries and Their Relation to Heat Balance, by A. L. Penniman, Jr., Consolidated Gas, Electric Light & Power Co., Baltimore, Md.

Morning—Technical Session (B)

Shaft Currents in Electric Machines, by P. L. Alger, General Electric Company, Schenectady, N. Y., and H. W. Samson.

Eddy Current Losses in Armature Conductors, by R. E. Gilman, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Tooth Pulsations in Rotating Machines, by T. Spooner, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Surface Iron Losses with Reference to Laminated Materials, by T. Spooner and I. F. Kinnard, both of the Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Afternoon

Dedication of the Moore School of Electrical Engineering at the University of Pennsylvania.

Evening

Entertainment and Dance.

Thursday, February 7

Morning—Technical Session (A)

Method of Testing Current Transformers, by F. B. Silsbee, Physicist, Bureau of Standards, Washington, D. C.

Recent Developments in Kilovolt-Ampere Metering, by B. H. Smith, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa. and A. R. Rutter.

Automatic Transmission of Power Readings, by B. H. Smith, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa., and R. T. Pierce.

Quadrant Electrometer for Measurement of Dielectric Loss, by D. M. Simons and W. S. Brown, both of the Standard Underground Cable Co., Pittsburgh, Pa.

Morning—Technical Session (B)

Recent Advances in the Manufacture and Testing of Static Condensersin Power Sizes, by R. Marbury, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Effect of Time and Frequency on Insulation Tests of Transformers, by V. M. Montsinger, General Electric Company, Pittsfield, Mass.

Insulation Tests of Transformers as influenced by Time and Frequency, by F. J. Vogel, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Short Circuits of Alternating-Current Generators, by C. M. Laffoon, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Afternoon—Technical Session

Economic Development of Step-by-Step Automatic Telephone Equipment, by P. G. Andres, Automatic Electric Co., Chicago, Ill.

High Quality Transmission and Reproduction of Speech and Music, by W. H. Martin, American Tel. & Tel. Co., New York, N. Y., and H. Fletcher, Western Electric Co., New York, N. Y.

Function and Design of Horns for Loud Speakers, by C. R. Hanna and Joseph Slepian, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Certain Features Affecting Telegraph Speed, by H. Nyquist, American Tel. & Tel. Co., New York, N. Y.

EVENING

Annual Dinner Dance

FRIDAY FEBRUARY 8, 1923

MORNING—TECHNICAL SESSION (A)

Measuring Methods for Maintaining the Transmission Efficiency of Telephone Circuits, by F. H. Best, American Tel. & Tel. Co., New York, N. Y.

Radio Telephone Signaling—Voice Frequency, by C. S. Demarest, American Tel. & Tel. Co., New York, Milton L. Almquist, and Lewis M. Clement.

Telephone Transformers, by W. L. Casper, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

An Electrical Frequency Analyzer, by Wegel, Moore and Dean.

MORNING—TECHNICAL SESSION (B)

Multiple System of Cooling Large Turbo-Generators, by Donald Bratt, Brooklyn Edison Co., Brooklyn, N. Y.

An Experimental Study of Ventilation of Turbo-Alternators, by C. J. Fechheimer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Importance of Brush Mounting, by P. C. Jones, Goodyear Tire and Rubber Co., Akron, Ohio

AFTERNOON

Visit to Bethlehem Steel Company.

EVENING

Entertainment and visit as guests of Lehigh Valley Section at Lehigh University.

MIDWINTER CONVENTION COMMITTEES

The personnel of the Midwinter Convention Committee is as follows: W. C. L. Eglin, Chairman, L. F. Deming, I. C. Forshee, G. A. Harvey, W. F. James, L. C. Lynch, Ross B. Mateer, William McClellan, L. W. W. Morrow, Harold Pender, Paul Spencer.

At a meeting of the general committee held on November 21st, chairman of several subcommittees were appointed as follows: Finance, F. J. Chesterman; Entertainment, J. C. Lynch; Registration, W. F. James; Inspection Trips, Paul Spencer; Publicity, L. F. Deming; Dedication of Moore School, Harold Pender; Transportation, I. C. Forshee.

Spring Convention Plans

Birmingham, Alabama will be the location for the Spring Convention of the Institute and the date is April 7th-11th. The hearty cooperation of the local committee in Birmingham with the Meetings and Papers Committee has brought about plans for a program which should attract electrical engineers from all parts of the country.

Hydroelectric developments and equipment, high-tension transmission lines and equipment, electric furnaces, oil circuit breakers, operation of interconnected systems, high-tension insulation, lightning arresters and relays are some of the topics which will be treated. It is planned to have authoritative papers presented on these topics by men representing the practises and opinions of all sections of the country so that very profitable discussions should result.

As a feature of the convention it is planned to stage a meeting on the electrical development of the South—What it has meant and what it will mean. Industrial leaders, legislators and utility executives will talk on various aspects of the topic and sufficient acceptances have been received to warrant the promise of a very successful meeting.

Nomination and Election of Institute Officers for 1924-1925

As provided in Section 19 of the Institute By-Laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1924, by the petition or by the separate endorsement in writing, of not less than twenty-five members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1924. For the conveniences of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available. A member is not limited in the number of candidates he may endorse in this manner.

The officers to be elected are: A President and a Treasurer for the term of one year each, five Vice-Presidents for the term of two years each (one from each of the odd numbered geographical districts), and three Managers for the term of four years each.

The five odd numbered districts from which Vice-Presidents are to be chosen at the May 1924 election are as follows:

1. North Eastern: Maine, New Hampshire, Vermont, New York, Massachusetts, Rhode Island, Connecticut.

3. New York City: Territory of the New York Section; also Canal Zone, Porto Rico and all foreign countries except Canada.

5. Great Lakes: Wisconsin, Michigan, Illinois and Indiana.

7. South West: Texas, Oklahoma, New Mexico, Kansas, Missouri and Arkansas.

9. North West: Washington, Montana, Oregon, Idaho. Utah and Alaska.

According to the revised Constitution, while one Vice-President must be elected from each of the five odd numbered districts, this does not debar members in one district, if they so wish, from nominating and voting for a candidate in another district. When the votes are counted the candidate for Vice-President having the largest vote in each district will be elected to that particular office for that district, irrespective of the fact that he may have polled a smaller number of votes than a candidate standing second in another district.

For the information of members the full text of revised sections of the Constitution and By-Laws applying to Officers, nominations, elections, etc., are printed below:

CONSTITUTION

SEC. 23. The officers of the INSTITUTE shall be a President, one Vice-President from each geographical district as defined in the By-Laws, twelve Managers, a Secretary and a Treasurer.

SEC. 24. The President, the Secretary and the Treasurer shall hold office for one year, the Vice-Presidents for two years and the Managers for four years. The President and Managers shall not be eligible for immediate re-election to the same office. No Vice-President or Manager who has served continuously in one or more offices, and whose combined terms shall have aggregated six years or more shall be eligible for immediate election to the office of Manager or Vice-President. At each Annual Meeting the President, the requisite number of Vice-Presidents to fill vacancies caused by expiration of terms, three Managers and the Treasurer shall be elected by the membership, and their terms of office shall commence on the first of August next succeeding their election................

SEC. 24A. At the election of Vice-Presidents held in 1921 there shall be elected one Vice-President from each geographical district, those from the odd-numbered districts to serve for one year each, and those from the even-numbered districts two years each. All Vice-Presidents elected thereafter shall serve for two years each. In the event of a change in the geographical districts, the Vice-Presidents then in office shall complete their terms. In case of revisions of the geographical districts, the Board of Directors shall have the power to elect a Vice-President from each district not represented to serve until the next election covering these districts.

BY-LAWS

SEC. 19. In addition to the names of the incumbents of office the Secretary shall publish on the form showing offices to be filled at the ensuing annual election in May provided for in Article VI, of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the

petition or by the separate endorsement of not less than twenty-five members, received by the Secretary of the Institute in writing by January twenty-fifth of each year; provided, however, that any candidate proposed for nomination by petition may withdraw his name by written communication to the Secretary, and any name so withdrawn prior to the printing of the form shall not be published.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the December and January issue of each year's JOURNAL and shall be reproduced on the form above referred to.

SEC. 21. There shall be ten geographical districts grouped as follows: (For the balance of this Section describing districts see By-laws and map.)

SEC. 21A. Should the territory of any Institute Section lie in more than one geographical district as defined above, then the entire territory of said Section shall be considered as belonging to the geographical district in which the headquarters of the Section are located.

Northwest Geographical District

A meeting of the Executive Committee of the Northwest Geographical District of the Institute was held in Portland, Oregon, on Wednesday afternoon, November 14. Vice-President H. T. Plumb of Salt Lake City, Chairman of the Committee, presided and all Sections in the District were represented, also one of the Student Branches. The Vancouver Section was also represented, in accordance with a suggestion made at the Sections Delegates Conference held at the Annual Convention at Swampscott last June, to the effect that representatives of the Vancouver Section meet with the Executive Committee of the Northwest District and representatives of the Toronto Section meet with representatives of the Northeastern District.

Many topics of interest to the various Sections were discussed, including the difficulties involved in maintaining attendance at meetings of the smaller Sections, enrolled Students and their relation to the Institute membership and the Section organizations, grades of membership, schedules and subjects of future meetings, etc. The meeting went on record as favoring an active campaign by the various Sections to bring about the transfer of members who are qualified, to higher grades of membership particularly from the grade of Associate to the grade of Member. Steps were taken with the object of making the membership of greater usefulness to enrolled Students of the various engineering schools. Portland Section will probably plan an excursion to visit the engineering show being organized by the Student Branch at the Oregon Agricultural College. Other Sections will consider similar cooperation with the Students. Various suggestions were made with the object of coming in closer contact with the student engineer, including the offering of a prize by a Section to the Student in the territory producing the best paper. No definite action was taken but the suggestion will receive further consideration.

All agreed that the meeting was a pronounced success and would result in great benefit by coordination of the activities to the Sections within the District.

Those present at the conference, in addition to Vice-President Plumb, were:

Portland: Messrs. Harry P. Cramer, Harold H. Cake, Lindsley W. Ross, John Bankus, B. B. Bessesen, R. J. Davidson, F. A. Murphy, H. H. Schoolfield, D. W. Proebstel. Salt Lake City: H. W. Clark. Seattle: Messrs. J. Hellenthal, Chas. A. Lund. Spokane: Messrs. E. R. Hannibal, J. Wimmer. Vancouver: Mr. A. Vilstrup. Oregon Agricultural College: Messrs. Merle P. Bailey, E. E. Bucher.

The visitors attended a meeting of the Portland Section on the evening of November 14.

VISITS BY VICE-PRESIDENT PLUMB

Following the Portland meeting Vice-President Plumb visited and spoke at meetings of the Sections at Vancouver, Seattle and Spokane.

Great Lakes Geographical District

A meeting of the Executive Committee of the Great Lakes District was held in the Committee Room of the Assembly Chamber of the Wisconsin Legislature, at Madison, Wisconsin, Saturday morning, November 17, 1923.

Those present were: Messrs. J. E. Kearns, of Chicago; George E. Wagner and R. G. Walter, both of Madison; Prof. Ellery B. Paine, of Urbana, Illinois; D. C. Pyke and C. A. Pfleiderer, Jr., of Indianapolis; S. H. Mortensen, of Milwaukee, Gordon B. McCabe, of Detroit; H. W. Meyer, of Minneapolis; and Vice-President R. F. Schuchardt, of Chicago, who presided.

The purpose of the meeting was to discuss experiences of the several sections which were thought might be of interest to other sections. The reports made by the representatives of the various sections were briefly as follows:

The Milwaukee Section finds it advantageous to meet jointly with the Milwaukee Engineers' Society, of which body the Section is a member. Monthly meetings are held by the Society and the several sections of national engineering societies take turns in directing these meetings, two of them each year being arranged for by the Institute.

Detroit has had two meetings thus far this season, one of them a get-together meeting, which was a dinner in which songs had a major part followed by dancing. The subject of their technical meeting was an electro-physical one and proved somewhat too "special" and particularly as the officers thinking that it would be along more popular lines had made no special efforts to get an audience primarily interested in physics. They feel the need of frequent meetings to appeal to industrial engineers of whom there are a large number in Detroit, and who will not ordinarily come to meetings that do not relate more closely to their own work. The need of live advertising with humor and plenty of human interest in its was emphasized.

Indianapolis had a dinner meeting jointly with the Mechanical Engineers in October and discussed the subject of public utilities. The program for the rest of the year is being made up and they are counting on another public utility paper and on a telephone paper by an engineer from the A. T. and T. The necessity for advertising the meetings and the desirability of using the newspapers, photographs of the speakers, etc., was mentioned.

The situation in Urbana, Illinois, is somewhat different from that of the larger cities. There are only about twelve or fifteen city members of the Institute and they find their joint meetings with the student branch, which are held once a month, to be more successful than separate meetings. They had had a talk by Prof. Morgan Brooks on electrification in Europe and America, Prof. Berg had spoken to them giving reminiscences of Dr. Steinmetz, and they are looking forward to an interesting program for the rest of the year. They aim to have subjects presented in a very popular way and frequently a large part of the audience consists of the towns people, including many women. The section is also making up its program for the balance of the year.

Prof. Chas. T. Knipp, of the University of Illinois, and Secretary of the Urbana Section, has a very interesting lecture with illustrating apparatus on sound, which is unusually interesting, and which may be available to other sections.

The Chicago Section arranges all of its meetings jointly with the Electrical Section of the Western Society of Engineers. The program is arranged at the beginning of the year and it is seldom that changes are made in it. Two meetings have already been held this year and an interesting program for the balance includes discussion of transmission cables, European progress in electrical development, a talk by Prof. Riggs, of Michigan, on the economics of engineering, and a meeting jointly with the Mining Engineers on a subject of common interest. The meetings are usually preceded by moving pictures, for about half an hour, on a subject of interest to engineers but not necessarily related to the subject of the evening's talk.

Attention was called to the fact that the Mid-Summer Convention in 1924 will be held at Evanston, a suburb adjoining Chicago on the north, and all sections were invited to send suggestions to Chairman Kearns of the Chicago Section with reference to this Convention.

The Minnesota Section meets in the Engineering Building of the University of Minnesota, but in general does not draw heavily from the student body. Two meetings thus far had dealt respectively with Rural Lines by Mr. S. B. Hood and the Electricity Supply Industry and the Engineer by R. F. Schuchardt. For the remainder of the program the Section is hoping to have an evening with astronomy; a talk from Mr. Lukeish; Mr. Mills of the A. T. and T.; a talk on the St. Lawrence waterway; Mr. C. E. Skinner on some phase of research; and another meeting will be given over to some general subject and an address by a leading banker. For February their annual dinner dance is scheduled. There are many other engineering societies in Minneapolis and St. Paul.

The Madison Section draws its membership from engineers in the city and from the University of Wisconsin faculty. They have four to six meetings a year and occasionally these are held jointly with the University Branch. They are looking forward to a meeting on astronomy, to a talk on economics of water power development in Wisconsin by Prof. Mead, and a general subject on engineers and engineering societies by Mr. John H. Cadby, Executive Secretary of the Wisconsin Utility Association.

In the general discussion which followed these reports it was suggested that one of the important things to be accomplished was to encourage more participation in the program from the floor, that is, more general discussion and particularly on the part of the younger members. Forum meetings were thought very excellent toward this end.

All of the Committee was urged to try to work out plans in each Section which would encourage more activity from the floor and then if they found any particular plan successful to tell the others about it. It was also thought to be a good plan to distribute the responsibility for meetings or for special features of meetings among the membership. More active interest in engineering education was also suggested. Milwaukee is planning a special meeting on this subject.

The suggestion was made that when visiting engineers from other cities happen to be in town at the time of a meeting members should make special efforts to have such visitors attend the meeting and perhaps also take part in the program to encourage the local engineers by bringing information or experience from outside to widen the interest in the meeting.

A very brief discussion was then had with reference to increase of membership activities and the plan of the Minnesota Section was described. Prospect lists are drawn up and assigned to members of the Committee and these members then personally see all those on their lists. The mails are not depended on for any of this work, as it has been found that letters without a personal visit are not very effective.

The meeting adjourned to the Madison Club where luncheon was served through the courtesy of the Madison Section.

Prizes for Papers Presented at Institute Meetings

The following report has been made, under date of November 17, by the Special Committee on Award of Prizes for papers presented before the Institute during the year 1922:

"The Transmission Prize was awarded R. J. C. Wood for his paper entitled '220-kv. Transmission System, Southern California Edison Company and Some 220-kv. Researches.' Honorable mention should be given H. B. Dwight for his paper entitled 'Electric Characteristics of Transmission Lines.'

"The First-Paper Prize was awarded to C. H. Van Asperen for his paper entitled 'Mechanical Forces on Busbars Under Short Circuit Conditions.' Honorable mention should be given to E. B. Shand for his paper entitled 'An Analytical Investigation of the Causes of Flashing of Synchronous Converters'."

The two prizes referred to above were established by the Board of Directors in 1921, and they each consist of $100 in cash and a suitable certificate.

The Transmission Prize is awarded each year to the "author of the paper that is designated by the committee of award as the most worthy paper dealing with the art of transmitting electrical energy over considerable distances, presented during the year by a member of the Institute at a meeting of the Institute or any of its Sections."

The First-Paper Prize is awarded each year to the "author of the paper which is designated by the committee of award as the most worthy original paper presented during the year at a meeting of any Section of the Institute, by a member of the Institute who has never before presented a paper before the Institute or any of its Sections."

Arrangements will be made, if possible, to present these prizes at the coming Midwinter Convention in Philadelphia, in February, 1924.

Edison Meets Medalists

Thomas A. Edison and six of the ten living men to whom the Edison Medal has been awarded were guests of honor at a luncheon given at the Engineers' Club on Friday, November 9, by Mr. Edward D. Adams, Chairman of the Edison Medal Committee of the American Institute of Electrical Engineers. Others in attendance were the members of the Edison Medal Committee of Award.

The Edison Medal was founded upon the initiative of an organization composed of associates and friends of Thomas A. Edison, who subscribed a trust fund for that purpose and invited the American Institute of Electrical Engineers to accept the responsibility of making the awards. By the terms of the Deed of Gift and the By-Laws of the Committee, this gold medal is awarded each year to a resident of the United States or Canada "for meritorious achievement in electrical science, electrical engineering or the electrical arts."

The award, which is one of the highest attainable honors in the engineering profession, is made by a committee of the Institute consisting of twenty-four members.

The medalists who were present were: Dr. Elihu Thomson of Swampscott, Mass.; Mr. Frank J. Sprague and Professor Michael I. Pupin of New York; Mr. Benjamin G. Lamme of Pittsburgh; Mr. W. L. R. Emmet of Schenectady; and Mr. Cummings C. Chesney of Pittsfield, Mass. The other living medalists who were unable to attend were: Messrs. Charles F. Brush of Cleveland; John J. Carty and Nikola Tesla of New York; and Robert Andrews Millikan of Pasadena, Calif. Three medalists, namely, George Westinghouse, William Stanley, and Alexander Graham Bell, are deceased.

Brief reports were made by Past President Jewett and Secretary Hutchinson on the presentation of the Edison Medal for 1922 to Dr. Robert Andrews Millikan at the Pacific Coast Convention of the Institute, held in Del Monte early in October, on which occasion Dr. Jewett made the presentation address from New York by means of trans-continental telephone lines and amplifying apparatus installed at Del Monte.

Brief addresses were made by Dr. Thomson, Professor Pupin and Mr. Gano Dunn, which are published in part below.

The culminating act at the luncheon was the presentation of a silver replica of the Edison Medal to Mr. Edison as a memento of the occasion, this being the only silver medal that has ever been struck from the medal dies. In presenting this replica, Chairman Adams said:

"As an expression of our great pleasure in greeting you here today in our electrical symposium, we hereby present you with a silver medal struck by the United States Mint from the Edison Medal dies, expressly as a souvenir for you and as a reminder of the many friends of twenty years ago who made this conference possible, and of those of today who most earnestly wish you a future of comforts, friendship, and achievements as

you yourself would welcome them as the crowning features of a useful and happy life."

Dr. Elihu Thomson, to whom the first medal was awarded in 1909 and who was introduced by Chairman Adams as a successful "eclipse chaser," explained that this title was probably conferred upon him by Mr. Adams on account of his experience in 1908 when he went with others to Steamboat Springs, Colorado, for the purpose of taking observations and photographs of a total eclipse of the sun Shortly before the eclipse was due a heavy cloud appeared, and Dr. Thomson succeeded in persuading a passerby in a Ford car of ancient lineage to take him out into the country in search of clear sky. After traveling at a precarious speed for twenty minutes he succeeded in finding a spot on a high ridge under clear blue sky about three minutes before totality, and was able to obtain an excellent view of the eclipse, which opportunity was denied to those who remained at Steamboat Springs.

Dr. Thomson spoke of the tremendous development in the physical sciences since his youth, and referred to the fact that he has lived to see the relationship of the chemical elements explained, also the relation of the lines of the spectrum to structure of the elements. He also referred to the researches that have resulted in the identification of the heat vibrations or electromagnetic waves throughout almost the entire scale up to a frequency including radio emanations, and remarked that every atom has gravitational power and therefore has its influence throughout the universe. In closing Dr. Thomson said: "If we had a world untorn by selfishness and insecurity of civilization there would be no limit to what man could accomplish on this earth through the applications of science."

Mr. Gano Dunn spoke feelingly of his contacts with and the encouragement received from Mr. Edison in the early days of the speaker's engineering experience. He then said:

The Chairman has assigned me the National Research Council. In the very early days that was Edison. His laboratory was a center towards which radiated all kinds of inquiry and from which came world affecting results.

The National Research Council established in 1916 by the National Academy of Sciences under its Congressional Charter and organized with the cooperation of the National scientific and technical societies of the United States, is doing on a large scale commensurate with the attention science is today receiving, the inspirational and educational work to which Edison so strikingly contributed.

Broadly speaking, it conducts no research but it protects and waters the roots of pure science on which all industrial research depends and by organization and large pecuniary resources from the Rockefeller and other foundations and from industrial sources, the disposition of which it influences and advises, it brings within the reach of the research worker, the opportunity to achieve and the aid of collateral inspiration and information, without which he might be barren. It aids in giving to industry the raw materials of industrial research.

Its new building with endowment, result of a $5,000,000 gift by the Carnegie Corporation, is rapidly nearing completion, opposite the Lincoln Memorial in Washington. A temple of science, its altars will daily expose to the public in actual operation, changing exhibits of the latest advances in the medical, mathematical, physical, chemical, biological, agricultural and psychological sciences.

There will be permanently in its rotunda, brought down by a great revolving coelostat eye in the dome, an image of the sun himself with his variable spots and all his flaming personality. A Foucault pendulum will remind of the rotation of the earth and of one of science's most beautiful demonstrations of method.

The torch that Edison carried into the darkness has lighted many torches. Research will grow and broaden for the use of man, and the supply of that intellectual curiosity which is one of his deepest satisfactions. With each great name added to the list of Edison medallists, the fame of research and of the Medal and of Edison will increasingly reverberate.

Dr. Michael I. Pupin, 1920 Edison Medalist, said:

Professor Thomson, referring to the electrical structure of the atom, says that every atom extends to infinity, and that, therefore, everybody is everywhere. This was Faraday's vision as far back as 1846. I quote now from a story which I wrote not very long ago:

"When I told her (my mother) of Faraday's vision, that all things extend to and exist in every spot of the universe at the same time and that, therefore, all things are in perpetual contact with each other, every star feeling, so to speak, the heart-beat of every other star and of every living thing, even the tiniest worm in the earth, she said:

'Faraday's science is that part of my religion which is described in the words addressed to God by King David:

'Whither shall I go from thy spirit? Or whither shall I flee from thy presence.'

God is everywhere, and where he is, there is every part of his creation."

Light, according to Faraday's vision was due to the activity of the lines of force proceeding from the atomic centers of force. This inspired Maxwell with the electromagnetic theory of light, and today this theory is not only confirmed but greatly extended into the electromagnetic theory of matter. In this theory the electron is the very foundation in the structure of the atom, and it is the principal object of all considerations in the new science, the science of electron-physics. But if the present ideas concerning the electrical structure of the atom prevail then another new concept in physics will soon share with the electron the attention of the physicist; it is the *magneton*. If hydrogen really consists of a positive center with a negative electron moving in one of many definite orbits around it then an atom of hydrogen must have a definite magnetic moment. Experiment confirms this view. There is strong hope that the study of the magnetic moments of atoms will soon give us a new science, the science of magneton-physics.

The remarkable permeabilities obtained by the scientists of the Western Electric Company with alloys of nickel and iron baffle the ingenuity of the best of us when we try to explain them in terms of the existing knowledge. But who dare deny today that the explanation will be a perfectly simple matter when magneton-physics had advanced as far as electron-physics has advanced?

I agree with Professor Thomson that this room is full of electrical waves traveling in all kinds of directions and in all possible phases of progression, and that we know today how to pick out any one of them selectively, but that we do not as yet know how to coordinate their activities and make them all pull together. This is the great problem of coordinating the non-coordinated energies in the universe. I quote again from my story referred to a minute ago:

The Greeks of old believed that the world started with a chaos, and that out of the chaos came the cosmos . . . Nothing also resembles that chaotic start of the world which the ancients conceived as does the activity of a young star, because nothing more completely illustrates lack of order and coordination . . . . consider our sun, as an illustration. Tiny energy units are projected from myriads and myriads of its atomic guns in haphazard fashion, apparently without any definite aim. These tiny energy units are propagated through space in a perfectly chaotic fashion, without a definite object in view as far as science can tell. But their fate and destiny are fixed and determined as soon as they arrive on mother earth and are caught by the leaves, the blossoms, and the ripening fruit . . . . and by the endless nets of the all embracing oceans. The chaotic, non-coordinated energy-swarms are thus imprisoned and made to work together with a definite aim and for a definite purpose. The joys and beauties of our annual seasons will tell you the story of this wonderful transformation of primordial energy from the chaos of the young stars, white hot with joy of life, to the cosmos of the old, cold and moribund earth . . . . . Terrestrial organisms have instrumentalities with which they coordinate the non-coordinated, thus bringing the order of old age out of the disorder of youth, final cosmos out of primordial chaos . . . . Progress means more complete coordination of all natural activities, the activities of the burning stars as well as of the cells in our terrestrial bodies. Call this progress evolution, or anything else you please, it certainly is there, and it leads to a more beautiful and a more perfect order of things.

But what are the instrumentalities by means of which terrestrial organisms coordinate the non-coordinated energy of our central star? The simplest and the shortest answer to this question is: Electrical Tuning. All our experience with radio operations and with absorptions of light and of heat encourages us in the belief that these coordinating instrumentalities operate in accordance with the laws of resonance and harmony.

I agree with Professor Thomson that all our progress in science will not advance the happiness of mankind, unless something is done to strengthen the spirit of man by eliminating the poisons of greed and selfishness. Now, the phenomena in the spiritual world resembles those in the physical world in the sense that they also are manifestations of non-coordinated activities. Progress in the spiritual world means coordination of the non-coordinated activities of the human souls. Nothing appears to me more natural than to believe that the coordinating instrumentalities in the spiritual world operate in accordance with the laws of resonance and harmony. Resonance and harmony with what? The answer is: with God, and with the best thoughts and sentiments of your fellowmen. The most powerful coordinating instrumentality operating in accordance with the laws of resonance and harmony in the spiritual world was discovered nearly two thousand years ago. It is: "Love thy neighbor as thyself." Its discoverer was crucified, and the world has done very little to put this great instrumentality into full operation, hence the spiritual chaos of today on this terrestrial globe. Let us not permit that our love of the beautiful laws of physical phenomena make us neglect the cultivation of the laws of the spiritual world. Without a knowledge of these and without a diligent application of this knowledge there will never be much happiness for man on this terrestrial globe.

Funds for Study of Engineering Education

The Carnegie Corporation on October 30th set aside the sum of $108,000 "for the purpose of making possible a study of engineering education under the direction of the Society for the Promotion of Engineering Education" to be available during the next three years. This realizes a project which has been developing with the Society during the past year and a half. A Development Committee was initially appointed to formulate an answer to the question, "What can the Society do in a comprehensive way to develop, broaden and enrich engineering education?" The Committee recommended the appointment of a Board for conducting an active campaign for the promotion of engineering in the light of the needs of the future as these needs may be developed. A general plan was proposed in which the engineering schools and engineering societies would be called upon to take an active part. The plan was submitted to the schools and received cordial endorsement. The project was then presented to Dr. Henry S. Pritchett of the Carnegie Corporation under whose direction a former study of engineering education was undertaken. This was the outcome of a movement inaugurated by the Society for the Promotion of Engineering Education continued by a joint committee from various societies in which the A. I. E. E. was represented; the result was the Report by Dr. C. R. Mann, issued five years ago.

Dr. Pritchett, formerly President of the Massachusetts Institute of Technology, took a sympathetic and constructive interest in the new project. As the result of numerous conferences a memorandum outlining the character and scope of the investigation to be initially undertaken was submitted to him and he replied in a letter endorsing the plan and saying that he would recommend that funds be provided. The memorandum and letter were presented at the annual Convention of the Society at Cornell University in June, where the project and the participation by the schools was enthusiastically endorsed.

Then followed the grant of funds by the Carnegie Corporation.

The Board of Investigation and Coordination, under whose direction the studies are to be conducted, consists of Dean M. E. Cooley of the University of Michigan, Past-President, A. S. M. E.; President F. W. McNair of the Michigan School of Mines, Past-President, A. I. M. & M.; Professor D. C. Jackson of the Massachusetts Institute of Technology, Past-President, A. I. E. E.; J. H. Dunlap, formerly of the Iowa State University and now Secretary of the A. S. C. E.; Dean P. F. Walker of the University of Kansas, President, S. P. E. E. and Chas. F. Scott of Yale University, Past-President, A. I. E. E., Chairman of the Board. Dean F. L. Bishop of the University of Pittsburgh, Secretary of the S. P. E. E. is also Secretary of the Board. Two additional non-engineering educators are to be added to the Board.

The Board has appointed W. E. Wickenden as Director of Investigations. He took over his new duties on a part time basis the middle of November and will have his whole time available within a few months. Mr. Wickenden graduated in sciences at Denison University in 1904. After a year's teaching he was a graduate student in physics and electrical engineering in the University of Wisconsin and then was instructor at Wisconsin until 1909 when he became Assistant Professor and later Associate Professor of Electrical Engineering at the Massachusetts Institute of Technology continuing until 1918. In 1917 he made a study of educational and personnel problems for the Engineering Department of the Western Electric Company and later became Chairman of its Personnel Committee. In 1921 he was transferred to the headquarters' staff of the American Telephone and Telegraph Company as Assistant Vice-President in charge of the recruiting and development of supervisory and technical personnel for the group of companies making up the Bell Telephone system. This work included the promotion of relations with universities and colleges and the supervision of the recruiting and introduction to the telephone business of approximately 2500 graduates in a three year period including 1500 graduates of engineering colleges. Mr. Wickenden's father was a Civil Engineer, well known in municipal, railroad and electric power circles in Northwestern Ohio. He himself, has had engineering experience in these several lines and in the field of illumination. He has been Chairman of the Educational Committee of the A. I. E. E. and of a corresponding committee of the American Management Association.

Headquarters have been secured in the Engineering Societies' Building thus making the physical provision for engineers given by Mr. Carnegie contribute to the administration of the Carnegie fund which is now provided for elevating engineering in its educational and inspirational aspects.

The Founder Societies have been requested to appoint two counsellors each to represent the several branches of the engineering profession in the investigation. The A. I. E. E. has appointed Dr. F. B. Jewett and Mr. Gano Dunn.

The scope and character of the work are set forth in the following memorandum which was submitted to Dr. Pritchett and his reply.

Memorandum

The Society for the Promotion of Engineering Education proposes during the next three years to make a discriminating study of the present state of engineering education.

In undertaking this work, the Society realizes the need of bringing it within a designated field in order that the investigation may lead to definite results. It is also clearly recognized that other studies on the same subject being made at this time should be related to that which the Society for the Promotion of Engineering Education has in view—particularly the investigation now under way by the National Industrial Conference Board, which approaches the subject from the standpoint of the man in industry who employs engineers and from the standpoint of practising engineers themselves. The inquiry proposed by the Society is primarily an educational study and will approach the subject from the educational point of view.

It is therefore proposed that the investigation of this Society

be directed to a study of the objects of engineering education and the fitness of the present day curriculum for preparing the student for his profession. It will study the process by which the curriculum of fifty years ago has come to its present form; it will seek to set forth the nature and the weakness of the curriculum as at present administered; and it will indicate such modifications or developments as would seem to make for a sound, well-balanced, and fruitful course of study for engineering students.

The following organization and program is suggested as one fitted to this investigation:

1. The inquiry shall be carried on under the general direction of a committee appointed by the Society for the Promotion of Engineering Education, with the understanding that this committee shall include at least two men chosen from outside the Society and the engineering profession, whose point of view will be primarily that of the trained teacher.

2. The active conduct of the study will be under the supervision of a Director appointed by the committee, whose office shall be in New York and, if possible, in the Engineering Building. The publication of the results of the study will be also in the hands of the Director.

3. The Director shall organize committees in the faculties of as large a number of engineering schools as may be practicable, who shall cooperate with the Committee and with the Society for the Promotion of Engineering Education in the prosecution of this study.

4. Inasmuch as a study of the engineering curriculum of American schools should include a knowledge of and comparison with the best schools of Europe, it is considered necessary that the Director of the Committee shall, as soon as his work is organized, visit the engineering schools of such European countries as may throw light upon the best methods in engineering education.

5. It is believed that the cost of this inquiry will amount to $24.000 the first year; $36,000 the second year; and $48,000 the third year, including the cost of publication. It is hoped that these sums may be obtained from such educational foundations as are interested in the prosecution of inquiries as important and as promising as this.

May 29, 1923.

Carnegie Corporation of New York,
522 Fifth Avenue
Office of the President

Charles F. Scott, Esquire, Chairman
Board of Investigation and Coordination
Society for the Promotion of Engineering Education

My dear Professor Scott:

I beg to acknowledge your letter of May the twenty-sixth submitting a memorandum concerning the proposed study of engineering education.

As you state in your letter, this memorandum follows closely the decisions reached in conferences we have held during the past year; and it commends itself to me most thoroughly as a well-planned and promising project, the completion of which will be of great service to engineering education. I should go even further and say that such a study seems to me essential at this time, and I can think of no better means of carrying it out than through the organization and program described in your memorandum.

It goes without saying that your choice of a director will be a matter of vital importance. No supervision by the committee in charge will take the place of an able, energetic and liberal-minded man who will give his whole time to an extensive study of this problem.

I am also convinced of the great significance of the plan through which the faculties of a number of engineering schools will cooperate, through committees, with the Society for the Promotion of Engineering Education in the prosecution of this study. Such cooperation will mean not only that the faculties of these schools will be in close touch with the study and will take part in the conclusions reached, but it will also help to create among teachers of engineering a hospitable attitude of mind toward the report of the Committee.

I shall take pleasure in commending this project to the President of the General Education Board and to the Adviser in Educational Research of the Commonwealth Fund, and I shall heartily recommend that the Carnegie Corporation participate in its support.

I am,

Very sincerely yours,
(Signed) Henry S. Pritchett

In Appreciation of Dr. Steinmetz

Expressions of appreciation of Dr. Steinmetz and his work have been published nationwide in the daily press and in the engineering and scientific fields. The A. I. E. E., probably closer to him than any other organization, most keenly feels the loss of its famous Past President. In addition to the official action taken by the Board of Directors at its meeting of October 26th, as outlined in the November Journal, the various Sections of the Institute have individually recorded their respect and admiration in resolutions adopted at local meetings. As an example of such a resolution the following is typical.

"We the members of this Section wish to place upon the permanent records of the Institute this expression of our respect and admiration for Charles Proteus Steinmetz whose death on October 26th brings to each of us a feeling of grief and personal loss.

"His going marks the passing of a master mind and the loss to humanity of one of the most human of its sons. Together with the multitude who have leaned on him for guidance we honor his memory and take comfort in the imperishable heritage which he has left to all mankind."

From the Institutions of Electrical Engineers in England and in Japan have come these cablegrams: "Institution of Electrical Engineers, London, send their sincere condolences to their American confreres on the death of Charles Proteus Steinmetz, one of the early pioneers and one of the greatest exponents of the science of electrical engineering. His fame is world wide, his work lives and will continue to live."

"We tender our sincere condolences on the death of Past President Dr. C. P. Steinmetz. Institution of Electrical Engineers of Japan."

Professor Harris J. Ryan, President of the Institute, speaks of Dr. Steinmetz as follows:

"Through life from early youth Dr. Charles Proteus Steinmetz was a profound student of the sciences, industries, linguistic arts and humanities. He worked constantly for their coordinated understanding in preparation for the solution of problems defined for progress. Through a decade he lead the advance of electrical engineers to the modern understanding of the electric circuit, the transformer, induction motor, alternator and high-voltage phenomena. Dr. Steinmetz assisted his brother engineers to an untold degree by his books, papers and discussions by his profoundly intelligent vision and by his example of persistent, ably directed enthusiasm."

The American Peace Award

REFERENDUM OF A. I. E. E. MEMBERSHIP IN JANUARY

The attention of the membership of the A. I. E. E. in the United States is again called to the fact that the Board of Directors of the Institute has agreed to the holding of a referendum of the A. I. E. E. when the Peace Plan finally selected by the Jury of Award is made known probably early in January 1924. Complete information relative to the Peace Award was published in the November Journal. Sincere cooperation by the membership is requested. Every member should give the plan earnest consideration, cast his vote and do so without delay after the receipt of the plan, ballot, etc.

Engineering Societies Employment Service

The first three months of operation of the Employment Service, under the new plan announced in the August Journal, gives the general impression that the new features have won friends and promise ultimate success when the plan has had opportunity to be developed.

Beginning December 1st a representative will interview the executives of organizations employing engineers, for the purpose of bringing the Service to their attention and will otherwise investigate opportunities for services of engineers.

A personal letter is being sent by the Secretary of each of the societies to a list of members who are employers of engineers, and all members who have a knowledge of openings where engineers may be employed are urged to advise the Employment Service.

The suggestions made regarding the new policies have been given very careful consideration. The changes were not made until after three years of study of the various problems by those

conversant with employment matters, including unemployed members and employers of engineers. From time to time as experience dictates some changes will probably be made but it is felt that the program is sound and, if given the support and cooperation of all members, both employers as well as those seeking opportunities, will steadily increase in value.

Information and statistics regarding operations of the Employment Service will be published in these columns from time to time.

Future Section Meetings

Boston.—December 11, 1923. Subject: "Common Sense and Mathematics in Engineering." Speaker: R. E. Doherty, General Electric Company.

New York.—December 19th. While the program for the meeting is not completely arranged as yet, the Program Committee wishes to announce that it has been successful in obtaining as speaker, Franklin H. Giddings, Professor of Sociology at Columbia. Prof. Giddings' subject will be "Human Engineering." It is hoped to have other speakers, directly engaged in large industries in what might be called the "personnel field," to add their experiences on this interesting subject, a subject which is receiving more and more attention of recent years.

The meetings scheduled for the balance of the year are as follows:

January 15. Jointly with A. S. M. E. and A. S. C. E., "New York Edison and Public Service Electric Companies' Systems"; February 27. Jointly with A. S. M. E. and A. S. C. E., on a Power subject. March 19. Jointly with A. S. M. E. and A. S. C. E., "City Planning and Transportation." April 16. "The Telephone Systems of Greater New York." May 21. Subject to be announced.

Pittsburgh.—December 11, 1923. The meeting will be held at the William Penn Hotel, at which meeting Dr. Joseph Slepian will be the speaker. He will discuss "The Mechanism of Breakdown of Sphere Gaps and Phenomena in Connection with Dielectric Discharge."

January 15, 1923. Subject: "The Recent Electrification of the West Leechburg Steel Co.". Speaker: Noble Jones, General Manager, West Leechburg Steel Co.

February 19, 1923. Subject: "Motor Ratings and Application." Speaker: C. W. Falls, General Electric Co.

Pittsfield.—December 7, 1923. Subject: "The Southern California Edison Company's 220,000-Volt System of Transmission." Speaker: D. H. Redinger, Big Creek Development Co., Southern California Edison Co.

January 3, 1923. Subject: "Paints." Speaker: F. P. Ingalls, Chief Chemist, Masury Paint Co.

January 17, 1923. Subject: "The Total Eclipse of the Sun, January 25, 1925." Speaker: B. R. Baumgardt.

February 7, 1923. Subject: "Transoceanic Radio." Speaker, F. H. Kroger.

Syracuse.—December 17, 1923. Subject: "Electrical Development in Retrospect." Speaker: Paul M. Lincoln, Director of the School of Electrical Engineering, Ithaca, N. Y.

Washington.—December 11, 1923. Subject: "Gyroscopic Stabilization Navigation and Steering of Ships." Speaker: H. B. Lea, Sperry Gyroscope Co.

Worcester.—December 20, 1923. Subject: "Industrial Control and Applications Thereof." Speaker: William C. Yates, General Electric Co.

1923 Power Test Codes Issued

The Hydraulic Test Code, the first to be completed of sixteen codes in course of revision by the Committee on Power Test Codes, has been published by the American Society of Mechanical Engineers.

Since December, 1917, the Committee has been at work upon this code, which is a revision of the Test Code for Hydraulic Power Plants and their Equipment published in 1915. To make this Code truly representative of the present practise the Committee was constituted as a joint committee with representatives of the American Society of Civil Engineers, the American Institute of Electrical Engineers, the National Electric Light Association, and The American Society of Mechanical Engineers.

W. F. Uhl headed the committee as chairman. The representatives of the A. I. E. E. were H. W. Buck, H. S. Putnam, and P. Torchio. Those desiring a copy of this Code may obtain it at a price of 80c. by addressing Publication Sales Dept., American Society of Mechanical Engineers, 29 West 39th St., New York.

National Exposition of Power and Mechanical Engineering

The National Exposition of Power and Mechanical Engineering will open at 2:00 p. m. on Monday, December 3, in the Grand Central Palace, New York. On the following days of the week the Exposition will open at noon and will close each day at 10:00 p. m.

The fundamental purpose of the Exposition is to bring together exhibits of manufacturers of power and mechanical equipment so that engineers and executives may have an opportunity for studying the latest devices. A series of educational exhibits will be offered. These exhibits will be devoted to the subjects of fuels, modern high-pressure boilers and modern locomotives. In addition each exhibitor is planning to present his apparatus in as instructive a manner as possible and the management is awarding certificates of merit for good exhibits. A comprehensive program of motion pictures will be shown throughout the Exposition.

The American Society of Mechanical Engineers and the American Society of Refrigerating Engineers will hold technical meetings during the week of the Exposition and members of these two societies will be admitted upon display of their badges or membership cards.

Syracuse Section Officers Appointed to Important State Committee

The conference of mayors and other city officials of New York State at its last meeting authorized the appointment of a committee to study street lighting and make recommendations for more efficient and more economical lighting. The Empire State Gas and Electric Association was asked to cooperate and name two members of the committee to work with the two named by the conference and the fifth member to be an expert of a manufacturing organization. The engineers named by the conference were Mr. A. E. Fisher, consulting engineer of the City of Rochester and Prof. Rich D. Whitney, head of the department of Electrical Engineering at Syracuse University and Consulting Engineer, Bureau of Gas and Electricity, City of Syracuse. Those named by the association were Mr. A. F. La Comtse of the Brooklyn Edison Co., Brooklyn, N. Y. and Mr. W. C. Pearce, engineer of the Syracuse Lighting Co., Syracuse, N. Y. The fifth member is Mr. A. B. O'Day of the Harrison, N. J. works of the General Electric Co.

The committee met for organization in Syracuse on Nov. 19th and at that time Prof. Whitney was elected chairman of the committee. It is of interest to note that Prof. Whitney is chairman and Mr. Pearce, secretary, of the Syracuse Section of the American Institute of Electrical Engineers.

American Engineering Council

NATIONAL CONFERENCE ON PUBLIC WORKS TO MEET IN WASHINGTON

The next step to be taken by the F. A. E. S. in the movement for the reorganization of the Department of the Interior, as outlined briefly in the November JOURNAL, is the summoning by the American Engineering Council of a National Conference on Public Works to meet in Washington on Wednesday, January 9, 1924. This conference will be one of a series of events lasting a week and will be attended by delegates from more than 200 national, state and local societies representing engineers, architects, constructors, manufacturers, chemists, geologists, economists, and business men.

The opening event of the week will be a meeting on Monday of the Committee on Procedure of the Council, followed on Tuesday by deliberations of the Executive Board. On Thursday and Friday the full membership of the American Engineering Council will convene for its annual sessions, facing an agenda presenting a wide range of social, industrial and scientific questions. A successor to President Mortimer E. Cooley of Ann Arbor, Mich., will be elected.

With the revival of the public works movement, local committees of the National Public Works Department Association will become active in New York, Washington, Chicago, Detroit, Cleveland and other cities.

DINNER IN HONOR OF MORTIMER E. COOLEY

University presidents, judges, engineers and men prominent in political life, gathered at a dinner in Detroit on November 23, paid tribute to Mortimer E. Cooley, dean of the engineering schools of the University of Michigan and retiring president of the Federated American Engineering Societies. Dean Cooley, at the end of nearly half a century of effort, was extoled as an engineer and educator of distinguished public service and one whose contributions to American life are destined to be of lasting influence.

Hundreds of engineers and representatives of other callings attended the dinner, which was given under the auspices of the Detroit Engineering Society, the Detroit Section of the American Society of Civil Engineers, the Detroit Section of the American Society of Mechanical Engineers and the Detroit-Ann Arbor Section of the American Institute of Electrical Engineers.

PUBLIC AFFAIRS PUSHED BY F. A. E. S.

During the Rochester meeting of the Executive Board much important work was accomplished for the engineering profession from the standpoint of the engineer in public affairs.

In the renewal of the campaign for a National Department of Public Works, the determined stand for an adequate reforestation program and the step toward the development of engineering education are to be found the items of most importance to the profession.

The Board feels that the engineering profession is vitally interested in maintaining and increasing our supply of timber and forest products near heavy consuming centers and that it is also interested in the maintenance of forest protection of our watersheds so that future power developments may be safeguarded, river navigation insured and agriculture protected.

Referring to its specially assigned function of furthering public welfare where technical knowledge and experience of engineers are involved, the Board stated in a carefully drawn resolution that it "regards the development of engineering education as a matter of outstanding importance to the engineering profession and to the welfare of the country. The Executive Board of the Federation is very heartily in favor of the project of the Society for the Promotion of Engineering Education to make a discriminating study of the present state of engineering education to be directed particularly to the objects of engineering education and the fitness of the present day curriculum."

Other important actions of the Board were its reaffirmation of its policy to assist on an adequate topographic mapping program and proper recognition of the engineering profession in the Public Health Service. The Patent Committee was authorized to determine the personnel and physical equipment needs of the Patent Office for improving efficiency. A committee was authorized for the purpose of making a special study of the Coal Commission's report from the standpoint of legislation required. A re-drafted bill on registration of engineers will be distributed informally. In the matter of labor-saving devices which the Federation was directed to investigate, it was decided to ask the Committee on Procedure to ascertain whether sufficient funds could be secured to finance an investigation of credit to F. A. E. S.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York, N. Y.

All members are urged to notify the Institute headquarters promptly of any change in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—C. C. Cobb, 209 W. 2nd St., Oklahoma City, Okla.
2.—Thomas R. Cummins, Autorite Products Co., Ontario, Calif.
3.—Mal L. Dodson, 1514 Van Buren St., Wilmington, Del.
4.—Alfred Fauquex, 154 W. 13th St., New York, N. Y.
5.—Charles E. Grant, Christie St. Hospital, Toronto, Ont., Can.
6.—John F. Greene, 5107 Cullom Ave., Chicago, Ill.
7.—Arthur S. Howard, 104½ West 10th St., Wilmington, Del.
8.—Robert J. Latorre, 157 Henry St., Brooklyn, N. Y.
9.—Donald T. Mason, 91 Wick Pl., Youngstown, Ohio.
10.—Milan S. Mitrovitch, Box 254, Roseville, Placer Co., Calif.
11.—Albert A. Partoes, Compania Mallorquina de Electricidad, Palma Balears, Spain.
12.—Otto Pramm, Hydro-Electric Pr. Comm., Toronto, Ont., Can.
13.—Wm. B. Schwartz, Apt. 1, 230 E. Fourth St., Atlanta, Ga.
14.—William J. Shannon, 1349 Fulton St., Brooklyn, N. Y.
15.—E. Slager, 4149-51 East 79th St., Cleveland, Ohio.
16.—E. D. Simpson, 4104 Agua Vista St., Oakland, Calif.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES, (OCTOBER 1-31, 1923)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

English for Engineers

By S. A. Harbarger. N. Y., McGraw-Hill Book Co., 1923. 266 pp., 7 x 5 in., cloth. $2.00.

The object of this textbook has been to make the study of English definite for the engineering student, and to stimulate his interest in a brief but comprehensive survey of the immediate uses to which English may be put by the engineer. It is intended to acquaint him with the sources for the study of English both for professional and cultural needs and interests.

Professor Harbarger discusses various practical matters of ordinary professional life, such as letters of application, order, inquiry and instruction; sales letters, dictation, the composition of technical articles and reports; and cultural reading. References for collateral reading are given in each chapter.

Small Electric Motors, D-C. A-C.

By E. T. Painton. Lond., & N. Y., Isaac Pitman & Sons, 1923. (Pitman's Technical Primers). 120 pp., diagrs., 7 x 4 in., cloth $.85.

The fractional horse-power motors, used so widely for driving portable tools, piano players, washing machines and other domestic appliances, although they operate upon the same principles as larger machines, often differ widely from the latter in their operating characteristics. This little book aims to indicate the general characteristics of small motors, to point out departures from the characteristics of large machines and to set out the general principles governing their performance.

The book is a welcome addition to the scanty literature on the subject. It should be of use to students and to users of small motors.

Armature Winding.

By David P. Moreton. Chicago, American Technical Society, 1923. 185 pp., illus., diagrs., 7 x 5 in., fabrikoid. $2.00.

This book sets forth in clear, simple language, modern practise in armature winding, and explains the theoretical principles involved. The book is intended for beginners and practical electricians and is especially planned for self-instruction.

Automatic Telephone Systems, Vol. 2; Auxiliary Services and Private and Branch Exchanges.

By William Aitken. Lond., Ernest Benn, 1923. 227 pp., illus., diagrs., 11 x 8 in., cloth. 35 s.

The second volume of this important treatise is concerned with the various auxiliary services of automatic telephone plants. Some of the important questions treated are substation equipment for working extension lines, working party lines and small installations for subscribers offices, branches, private installations, etc. An appendix supplements the first volume by describing several new pieces of apparatus. The work is very fully illustrated with diagrams of the circuits and is a thorough record of British practise.

Bibliographie Technique. Publication Mensuelle. 1923.

By A. Louis Vermandel. Bruxelles, Office International de Documentation Technique. Subscription price 125 fr. a year.

The latest activity undertaken by the International Institute of Bibliography is the publication of a guide to current technical periodicals. Publication began with the periodicals for January 1923.

The index covers engineering and industry, and the associated sciences. No list of the periodicals indexed is supplied, but they seem to include the more important American and European publications. The index is classified by the decimal scheme of the Institute. The bibliography is issued in loose leaves, printed on one side so that entries may be clipped for filing on cards and is issued in typewritten form at present for economy's sake.

Chemical Resistance of Engineering Materials.

By Marston Lovell Hamlin, & Francis Mills Turner, Jr. N. Y., Chemical Catalog Co., 1923. 267 pp., diagrs., tables, 9 x 6 in., cloth. $5.00.

This book is a collection of information about the behavior of metals, wood, cement, textiles and other structural and engineering materials, when exposed to the action of chemicals. Its purpose is to assist the engineer called upon to build chemical plants, in the selection of appropriate materials for piping, containers and other apparatus. Bibliographies are included, as well as a collection of useful tables.

Crain's Market Data Book and Directory of Class, Trade and Technical Publications.

3d edition, 1923. Chic., G. D. Crain, Jr., 1923. 497 pp., 9 x 6 in., cloth. $5.00.

This book aims to present statistical and market data about the various industries, trades and professions, for the purpose of enabling an advertiser or merchant to obtain a picture of the field as a whole. An important feature ot the book is the lists of publications covering each classification. These lists include all the important trade journals, and give the principal items of information desired by advertisers.

Electrodynamic Wave-Theory of Physical Forces, Vol. 2; New Theory of the Aether.

By T. J. J. See. Lynn, Mass., Thos. P. Nichols & Son Co., 1922. 259 pp., illus., plates, diagrs., port., 11 x 9 in., paper. $10.00.

This volume contains ten mathematical memoirs, most of which have appeared in recent volumes of the Astronomische Nachrichten. They continue the exposition of Professor See's views of the cause of universal gravitation and the theory of the chief forces of nature which he has evolved.

Elementary Principles of Lighting and Photometry.

By John W. T. Walsh. N. Y., E. P. Dutton & Co., 1923. 220 pp., diagrs., 9 x 6 in., cloth. $4.50.

This book aims to provide a simple guide to the solution of the problems most commonly met with in lighting engineering and to give both an explanation of the faults which experience has shown it necessary to avoid and of the means available for the attainment of a satisfactory result in any given case. The book is intended for electrical and gas engineers, architects, factory managers and others called upon to consider matters of illumination, rather than for specialists in this field. The information is

presented in readable form, requiring no previous knowledge of the subject.

Engineering Non-Ferrous Metals and Alloys

By Leslie Aitchison and William R. Barclay. (Oxford technical publications). 300 p., illus., diagrs., tables, 9 x 6 in., cloth. $7.00. (Gift of Oxford University Press. American Branch).

This book aims to supply engineers and manufacturers with accurate, useful information on non-ferrous metals and alloys. Throughout the maker and user are kept in mind, and the information selected and the method of presentation are those that fit his needs.

The first section of the book deals with the non-ferrous metals and alloys generally. The reasons for their use in engineering, their constitution, casting, working, heat treatment, mechanical properties and the methods of testing them are described and explained. Section two takes up individual metals and alloys in some detail. The alloys of copper, aluminum and of nickel, together with some miscellaneous alloys, are included. The final chapter discusses the choice and specification of an alloy.

Advanced Practical Physics for Students.

By B. L. Worsnop & H. T. Flint. N. Y., E. P. Dutton & Co., 1923. 640 pp., illus., 9 x 6 in., cloth. $8.00.

The course of practical physics described in this book is based upon that followed in King's College, London, by students preparing for an Honors degree. It is intended, however, also for use by a wider circle of students. The experiments included cover the subjects customarily included and the methods are given in detail. Each experiment is provided with a short theoretical treatment which will enable the student to perform it without immediate reference to theoretical treatises.

Friction.

By T. E. Stanton. N. Y., Longmans, Green & Co., 1923. 183 pp., diagrs., tables, 9 x 6 in., cloth. $4.20.

Contents: Introduction. Viscosity of Fluids. External Friction of Fluids. Fluid Friction of Lubricated Surfaces. Boundary Friction of Lubricated Surfaces. Solid Friction. Rolling Friction. Friction and Heat Transmission. Index.

In the past it has been customary to treat the various phenomena which can be grouped under the term "friction" more with reference to the particular branch of mechanics with which the frictional effect is associated than as intimately related manifestations of certain properties of matter. In the present book the author has adopted the view that friction is an essentially molecular phenomenon, best studied as a distinct branch of mechanics; and to facilitate this has collected in a single volume the results of modern investigations into the nature and laws of friction. The book is intended for engineers and research workers in engineering and the allied sciences.

Fundamentals of Welding, Gas, Arc and Thermit.

By James W. Owens. Cleveland, O., Penton Publishing Co., 1923. 659 pp., illus., 9 x 6 in., cloth with leather back and corners. $10.00.

A number of years ago the Bureau of Construction and Repair of the Navy undertook a special study of the art of fusions welding. With this work Mr. Owens has been connected from the beginning, and in charge of it for some years. This book based on his experience also makes use, by permission, of the results obtained by the investigations of the Navy and includes the matter previously published confidentially by it.

The book is a complete, practical manual on its subject. It sets forth the relative merits of different methods and their adaptability to different materials, the apparatus used, the preparation of the joints, the methods of welding, inspection, etc. Standard welding specifications are included.

Die Gleichstrommaschine, Vol. 1; Theorie, Konstruktion und Berechnung.

By Franz Sallinger. Berlin u. Leipzig, Walter de Gruyter & Co., 1923. 128 pp., diagrs., 6 x 4 in., boards. .25.

The first of two small volumes on the construction and properties of direct-current generators, this book contains the essential data upon design and construction. The exposition has been made as simple as possible and should be comprehensible to any one acquainted with the physical foundations of direct-current engineering and with simple algebra. The book is intended as a simple manual for beginners and for those interested in the subject, but without technical training.

Industrial Filtration.

By Arthur Wright. N. Y., Chemical Catalog Co., 1923. (Modern library of chemical engineering, vol. 1). 336 pp., illus., 9 x 6 in., cloth. $5.00.

This volume, one of a series of works on chemical engineering, deals with industrial practise in filtration. The intention of the author is to describe actual practise and present day equipment, and to record minor details of interest to the operator, which usually are not presented in books on the subject. The book presents first the theory of filtration. This is followed by the mechanics of filtration, where various filters of different types are described and criticized. Section three, filter practise, describes the applications of filters in industry.

Internal Combustion Engines, Theory and Design.

By Robert L. Streeter. 2d edition. N. Y., McGraw-Hill Book Co., 1923. 443 pp., illus., diagrs., 9 x 6 in., cloth. $4.00.

This edition has been thoroughly revised by the author, with the assistance of several other engineers who have contributed chapters on their specialties. The book is thus brought in line with present practise in design and construction and covers small gas and gasoline engines, automobile engines, large gas engines and oil engines. A chapter is devoted to the Humphrey gas pump.

Mathematical Theory of Relativity.

By A. Kopff. N. Y., E. P. Dutton & Co., 1923. 214 pp., 8 x 5 in., cloth. $3.20.

The present introduction to the theory of relativity as expounded by Einstein arose out of a series of lectures delivered at Heidelberg in 1919-20. The object of this work is to reproduce in the simplest possible terms the investigations that have been conducted into the foundations of this theory and as a consequence the treatment is necessarily of a mathematical nature. The mathematical and physical equipment required for study of the book is approximately that acquired during the first few terms of a college course.

Practical Experience in Electrical Prospecting.

By Hans Lundberg. Stockholm, P. A. Norstedt & Soner, 1923. (Sveriges geologiska undersokning. Ser C. Avhandlingar och uppsatser, no. 319. Arsbok 16 (1922) no. 9). 37 pp., plates, maps, 9 x 6 in., paper. 2,00 kr.

Magnetic methods of prospecting were adopted in Sweden long ago and have been developed to a high degree of usefulness in examining magnetic ores which have no outdrops. The absence of similar methods for non-magnetic ores has been felt keenly and attempts have been made, since 1906, to develop practical ones. In 1918 a method of real importance was attained. Since that date the author of this brochure has been engaged in developing and improving the method, and he here presents an account of the investigation made on large ore-fields in Sweden, where the method has led to the discovery of large masked deposits of ore.

Principles of Direct-Current Machines.

By Alexander S. Langsdorf. 3d edition. N. Y., McGraw-Hill Book Co., 1923. (Electrical Engineering Tests). 470 pp., illus., diagrs., 8 x 6 in., cloth. $4.00.

Intended to provide junior and senior students of electrical engineering with a reasonably complete treatment of the fundamental principles that underly the design and operation of all types of direct-current machinery. No radical changes from the previous edition have been made in either content or treatment, but some alterations and additions have been introduced, to make the text clearer.

La Radiotelephonie.

By Carlo Toché. 2d edition. Paris, Gauthier-Villars et Cie., 1923. 120 pp., illus., diagrs., 10 x 6 in., paper. 10 fr.

The aim of this book is to give the general public with no special scientific knowledge a clear idea of the principle of radiotelephony, of its apparatus and of the methods of building and operating receiving stations. A chapter is devoted to the applications of telephony and its future possibilities.

Past Section and Branch Meetings

PAST SECTION MEETINGS

Akron.—October 26, 1923. Engineers of the Ohio Insulator Co. gave short talks and demonstrations on "Properties of Good Porcelain and Commercial Insulator Tests, with Examples Showing the Ability of Modern Insulators to Withstand Severe Conditions." Mr. A. O. Austin, the principal speaker, was assisted by Messrs. Ray Higgins, who spoke on the "Ceramics of Insulators;" O. G. Calland, who spoke on "Inspection;" and Ralph Higgins, who explained the electrical connections of the equipment used in the high-voltage laboratory demonstrations, Attendance 350.

Baltimore.—October 19, 1923. Preceding the meeting there was a dinner at the Southern Hotel. Subject: "Machine Switching." Speaker C. A. Robinson, Chief Engineer, C. & P. Telephone Co. Attendance 110.

October 20, 1923. Inspection trip to the Liberty Exchange, at which there were 50 members present.

Cincinnati.—October 11, 1923. A paper on "Self-Start Polyphase Motors" was presented by Justin Lebovici, Chief Engineer, Triumph Electric Co., Cincinnati. He traced the development of the self-start motor and emphasized the advantages in its application. Discussion followed. Attendance 55.

November 8, 1923. Meeting was held in the Assembly Hall of the Union Gas & Elec. Co. Subject: "Responsibility of Insulation in Superpower Development." Speaker: C. L. Fortescue, Manager of Porcelain Insulation and Transmission, Engineering Dept. Westinghouse Elec. & Mfg. Co. Through the courtesy of the Cincinnati & Surburban Bell Telephone Co., loud speakers were installed in the Assembly Room. Attendance 109.

Cleveland.—October 18, 1923. The meeting was held at Hotel Statler. A business meeting preceded the presentation of a paper on "Economic Features of the Development of Superpower in Ohio," by L. G. Tighe, Superintendent of the Northern Ohio Traction Co. Discussion ensued, in which the following participated: Messrs. Wallau, Cooper, Dates, Kositzsky, Kale, Huff and Grove. Attendance 100.

Columbus.—October 26, 1923. Business meeting preceded the evening's program. Subject: "Better Automobile Headlighting" and "The Importance of Accurate Equipment and Proper Adjustment," by R. N. Falge and W. C. Brown, of the National Lamp Works of the General Electric Co. of Cleveland. Before the talk a motion picture "A Trip through the Laboratories of the General Electric Co. with Thomas A. Edison" was shown. An interesting discussion followed the paper, in the course of which many types of headlights were shown. The meeting was a joint one with the Columbus Chapter of the Illuminating Engineering Society. Attendance 56.

Connecticut.—Nov. 7, 1923. The meeting was held at Community House, Norwich. Chairman Everit explained the aims and purposes of the A. I. E. E. and the desirability of its expansion in Conn. W. C. Phillips, Electrical Engineer, Stone & Webster, Inc., Boston, spoke on "Motorizing the Factory, and Power Factor Correction." Discussion followed. Attendance 90.

Denver.—October 19, 1923. Preceding the meeting there was an informal dinner at the Adams Hotel. A business meeting was held, after which W. S. Murray, speaker of the evening, made an address on "Superpower Systems for the Joint Use of Industries and Railways." Attendance 75.

November 2, 1923. This meeting was held in honor of Robert M. Spurck, Designing Engineer of the Oil Circuit Breaker Department of the General Electric Company of Schenectady. Mr. Spruck gave an illustrated lecture on the "Design and Characteristics of Oil Circuit Breakers," which was followed by discussion. C. J. Wheatlake was called upon to tell his personal recollections of Dr. Steinmetz. A resolution of appreciation of Dr. Steinmetz was adopted. Attendance 45.

Erie.—October 16, 1923. Subject: "Electric Arc Welding." Speaker: James F. Lincoln, Vice-President, Lincoln Electric Co., Cleveland, Ohio. Attendance 71.

Fort Wayne.—October 19, 1923. Motion pictures were shown entitled: "Tumbling Waters," and "Roads to Wonderland," from the Dept of Agriculture; "Up and Over" and "Play Days at Banff," from the Canadian & Pacific Railway Co. The speaker of the evening was A. J. Francis, Sales Mgr. of the Fractional h. p. Motor Sales Dept., General Electric Company, who made an address on "Making Our Marks on the Other Side." After the program the Entertainment Committee served light refreshments. Attendance 65.

Indianapolis-Lafayette.—October 24, 1923. This was a joint meeting with the A. S. M. E., which was preceded by an informal dinner at the Lincoln Hotel. Prof. George H. Shephard of Purdue University, gave a talk on "Factory Management." Attendance 41.

Lehigh Valley.—October 18, 1923. A dinner was held at the Pomfert Club, at which there were 35 members present. Messrs. Harvey, Beaver, and Perry talked on the A. I. E. E. The subject of the evening's discussion was "The Electrification of Steam Railways." The speakers were: H. K. Smith, Railway Engineer, Westinghouse Elec. & Mfg. Co., whose special phase of the subject was "Heavy Traction Electrification," and C. A. Burcaw, Transportation Division, Westinghouse Elec. & Mfg. Co., who spoke on "Electrified Operation of Suburban Service and Heavy Freight Pusher Service in the Vicinity of Philadelphia. Attendance 90.

November 16, 1923. The Eastern Penn. Electric Company gave a dinner to the Section at the Schuylkill Country Club, previous to the meeting. The following engineers of the J. G. White Engineering Corp. were called upon to describe the new plant of the Eastern Penn Electric Company at Pine Grove; C. A. Greenbridge, M. M. Sanderson, Messrs. Holland and Gray, B. A. Milner, W. H. Lesser, N. G. Reinicker. Attendance 202.

November 17, 1923. Inspection trip to Pine Grove power plant.

Los Angeles.—September 18, 1923. This section was host to seven other technical societies, The American Association of Engineers, The Mechanical, Chemical, Mining and Civil Engineers, Architects, and Landscape Architects. Dr. C. P. Steinmetz was the speaker of the evening, taking as his subject "The Electric Power Industry." Approximately 2000 people were present, and many were turned away for lack of space.

Lynn.—November 6, 1923. This was a social meeting, at which Mr. Charles Donelan of the Boston Traveller entertained with humorous stories, and moving pictures were shown. Music was furnished by the General Electric Apprentice Orchestra. Attendance 270.

Minnesota.—October 24, 1923. Subject: "The Engineer and the Electricity Supply Industry." Speaker: R. F. Schuchardt. Slides illustrated the lecture, and discussion followed. Attendance 150.

Philadelphia.—October 17, 1923. Subject "Making the Most of the Line." Speaker: Frank B. Jewett, Vice-President and Chief Engineer, Western Electric Company. Attendance 170.

Pittsfield.—October 18, 1923. Social meeting. Attendance 200.

November 6, 1923. Subject: "Davis Bridge Project." Speaker: J. J. Baker, Resident Agent, Whittingham, Vt. Attendance 300.

November 15, 1923. Subject: "Inventions and Patents." Speaker: A. A. Buck.

November 22, 1923. Subject: "The Influence of Modern Naval Warfare on International Relations."

Portland.—October 24, 1923. There was a short business meeting. Francis H. Murphy, of the Portland Railway, Light & Power Co., spoke on "The Relationship of the Local Sections of the A. I. E. E. and the N. E. L. A. to Their Parent Organization and the Oregon Technical Council." The talk was illustrated by charts. E. E. F. Creighton presented a paper on "Lightning and Continuity of Service." Discussion followed. Attendance 63.

Rochester.—November 2, 1923. Subject: "Inductive Co-ordination from an Engineering Standpoint." Speaker: Frank F. Fowle, Consulting Engineer. Attendance 85.

Schenectady.—October 19, 1923. It was announced that a regional prize would be offered for the best paper, to a person not having previously presented a paper. Dr. Lionel Fleischmann, of the A. E. G., Germany, made a few remarks on problems of high current rectification in Germany. Dr. A. W. Hull, of the Research Laboratory of the General Electric Company, spoke on "The Functions, Applications and Construction of the Various Types of Vacuum Tubes." Attendance 225.

November 2, 1923. Subject: "The Function of Patents." Speaker: Arthur A. Buck, of the Law Department of the General Electric Company. Discussion followed. Attendance 120.

Seattle.—October 17, 1923. Subject: "Development of the Underground Distribution System of the Puget Sound Power & Light Company, in Seattle." Speaker: Magnus T. Crawford. Attendance 65.

October 25, 1923. Special meeting to hear E. E. F. Creighton, Research Engineer, General Electric Co., who spoke on "The Development of the Lightning Arrester and Protective Equipment from its Early Days to the Present Date." Discussion followed. Attendance 87.

St. Louis.—October 17, 1923. Joint meeting of the Associated Engineering Societies of St. Louis, at the Engineers Club. Subject: "The Wired Wireless System of the Union Electric Light and Power Company." Speaker: Prof. R. S. Glasgow, Asst. Prof. of Electrical Engineering, Washington University. Attendance 61.

Springfield.—September 28, 1923. Subject: "The Manufacture of High Grade Instruments." Speaker: A. J. Lush, President, Rauson Electrical Instrument Co. Attendance 22.

Toledo.—October 24, 1923. Dinner meeting at the Waldorf Hotel. Election of officers as follows: Gilbert Southern, Chairman; Ira B. Matthews, Vice Chairman; Max Neuber, Secretary and Treasurer. Attendance 17.

Toronto.—October 19, 1923. Subject: "The Recruiting and Training Methods in a Large Electrical Industry." Speaker: John Mills, Educational Director, Western Electric Company. Attendance 73.

November 1, 1923. Joint meeting with the Toronto Branch, Engineering Institute of Canada, Toronto Section, A. S. M. E., Toronto Branch, Canadian Institute of Chemistry, and the Society of Chemical Industry. Hon. Justice Riddell spoke on "Expert Evidence." Attendance 260.

Urbana.—October 19, 1923. Subject: "Railway Electrification in Europe and America." Speaker: Prof. Morgan Brooks. The lecture was illustrated. H. A. Brown gave a brief report of the A. I. E. E. Convention at Swampscott, Mass. Attendance 175.

November 7, 1923. Subject: "Reminiscences of Steinmetz." Speaker: E. J. Berg, of the General Electric Co. Attendance 330.

Utah.—September 19, 1923. Subject: "Protective Devices and the Continuity of Electric Service." Speaker: E. E. F. Creighton, Research Engineer, General Electric Co. Discussion followed. Attendance 60.

September 28, 1923 Subject: "Recent Developments in Radio Communication, with Special Reference to Carrier Currents for Power Dispatching." Speaker: C. C. Jackson, Westinghouse Electric & Mfg. Co. Lantern slides were shown. Attendance 55.

October 8, 1923. Joint meeting with the Utah Engineering Council. Subject: "Electricity and Civilization." Speaker: Charles P. Steinmetz, Chief Consulting Engineer, General Electric Co. A public address system was used in the hall. Attendance 820.

Vancouver.—October 26, 1923. Subject: "Pumping Equipment for the Sumas Reclamation Project," Speaker: A. C. R. Yuill. The lecture was illustrated by a large number of photographs taken during construction and after completion of this project. This was a joint meeting with the Vancouver Branch of the Engineering Institute of Canada. A motion was adopted expressing the sympathy of the Section with those to whom the death of Dr. C. P. Steinmetz was a personal loss. Attendance 55.

Washington.—October 9, 1923. The meeting was held at the Cosmos Club. Subject: "The Caribou Hydroelectric Development of the Great Western Power Co., California." Speaker: Albert A. Northrup, of Stone & Webster, Inc., Boston. Discussion followed and refreshments were served. Attendance 165.

October 12, 1923. Excursion to Davis Bridge, in which about 40 people participated.

Worcester.—November 1, 1923. Subject: "Some of the Recent Marvels of Radio." Speaker: G. Y. Allen, Radio Engineer, Westinghouse Elec. & Mfg. Co. A motion picture "The Mystery Box," was shown. Attendance 150.

PAST BRANCH MEETINGS

Alabama Polytechnic Institute.—October 13, 1923 General discussion of plans for the year. No program. Attendance 26.

University of Arizona.—October 25, 1923. Prof. Paul Clarke spoke on "The Advancement of Electrical Engineering." A two-reel moving picture on transformer and meter testing was shown, after which there was a talk by Mr. Moyle. Social hour followed the meeting. Attendance 30.

University of Arkansas.—October 9, 1923. Subjects: "Plans and Purposes of the A. I. E. E. for the Coming Year," by J. A. Cunningham; "The University of Arkansas Broadcasting Station," by R. C. Mason; and "The Pullman Plant," by Porter Cleveland. Attendance 21

October 31, 1923. Subjects: "Engineering Exhibit at the State Fair," by George Whitlow; "Electrified Railroads," by L. G. Lovell; "Prevention of Waste in Industries," by Ed. Parkes. Attendance 17.

Armour Institute of Technology.—October 4, 1923. Professor Snow, of the Department of Electrical Engineering, spoke on the advantage of membership in the A. I. E. E. Attendance 26.

October 18, 1923. Subject: "Electricity, from Coal Pile to Consumer." Speaker: Mr. E. F. Bracken, General Inspector of Substations for the Commonwealth Edison Co. Attendance 36.

Bucknell University.—September 28, 1923. Subjects: "The Features of Electrical Control," by R. E. Lepperd; "The Evolution of the Transformer," by H. E. Schaffer; "The Problems and Duties of a Design Engineer," by H. S. Saunders.

All the speakers were of the Westinghouse Electric & Mfg. Co. Attendance 55.

October 22, 1923. Business meeting and election of officers as follows: Elliott S. Hopler, President; Murdo J. MacKenzie, Vice-President, Frank H. Brown, Secretary-Treasurer. Prof. W. K. Rhodes gave a talk on the purposes of the A. I. E. E. Attendance 35.

California Institute of Technology.—November 6, 1923. Subject: "Million-Volt Transformer Designed for the High-Tension Laboratory of the California Institute of Technology." Speaker: Prof. R. W. Sorensen. Prof. Sorensen gave a report of the convention of the A. I. E. E. at Del Monte, Cal. Attendance 47.

University of California.—October 10, 1923. Business meeting. T. A. Reid, of the Westinghouse Electric & Mfg. Co., gave a talk on "Industrial Heating." Attendance 34.

October 24, 1923. Initiation of 57 new members. Attendance 96.

October 31, 1923. Subject: "The Colorado River Project." Speaker: Robert Sibley. Attendance 91.

Carnegie Institute of Technology.—October 10, 1923. Business meeting and election of Executive Committee. There was a talk by Mr. Skinner, Secretary of the Pittsburgh Section, on the advantages of membership in the A. I. E. E., local and national. Social meeting followed. Attendance 29.

November 7, 1923. Subject: "Supervisory Control of Apparatus for Automatic Substations," by R. J. Wensky, Switchboard Engineer, Westinghouse Electric & Mfg. Co. Attendance 125.

Case School of Applied Science.—October 12, 1923. Election of officers as follows: H. P. Davis, Chairman; Geo. Geyser, Secretary; W. B. Ash, Vice-Chairman; L. G. Davis, Treasurer. Attendance 50.

University of Cincinnati.—October 11, 1923. Subject; "The Self-Start Polyphase Induction Motor." Speaker: Justin Liebovici, Electrical Engineer for the Triumph Electric Co. Attendance 74.

October 18, 1923. Subject: "Commercial Value of Abstract Research." Speaker: C. E. Theiss, Research Engineer, Tanners Council of America. Attendance 34.

Clarkson College of Technology.—October 16, 1923. Election of officers as follows: L. L. Merrill, Chairman; E. T. Augustine, Secretary; William Raeder, Treasurer. Einstein's "Theory of Relativity" was discussed.

November 13, 1923. Business meeting, and discussion of "Armature Winding." Attendance 24.

Colorado Agricultural College.—September, 1923. Election of officers as follows: Frank Ayres, President; Charles Sinnock, Vice-President; Lyndal Hands, Secretary and Treasurer. Business meeting followed. Attendance 14.

October 2, 1923 Two motion pictures were shown: "The Electric Meter" and "Back to the Farm." Attendance 40.

Denver University.—October 5, 1923. Subject: "Applications of Electricity to the Moving Picture Industry." Speaker: C. H. Diller. Attendence 11.

November 2, 1923. A motion picture "Railroad Electrification" was shown, by courtesy of the Westinghouse Electric & Mfg. Co. Attendance 46.

Drexel Institute.—October 31, 1923. Election of officers: Harvey Shelley, President; Alfred Geiklu, Vice-President; David McDowell, Treasurer; David Michelson, Secretary. Arthur C. Freeman gave a talk on his war work as plant engineer for the United States Shipping Board, and what he considered the three fundamentals of engineering. Luncheon was served. Attendance 23.

Georgia School of Technology.—November 1, 1923. Subject: "The A. I. E. E. and the Value of its Membership." by Mr. Hurault, Supervisor of the Georgia Ry. and Power Co. lines. Attendance 25.

Kansas State Agricultural College.—October 8, 1923. Subjects: "High-Tension Installations," by O. D. Hunt, and "Summer Work with Commonwealth Edison Co., Chicago," by L. Baty. Attendance 47.

October 22, 1923. Subjects: "Automatic Train Control on A. T. & S. F. Railroad," by F. S. Wallbridge, and "Summer Work in Westinghouse Electric & Mfg. Co.," by I. C. Bushey. Attendance 57.

Kansas University.—October 25, 1923. Business meeting and motion picture "The King of the Rails." Attendance 69.

University of Kentucky.—Business meeting and election of officers: Kobert R. Smith, Chairman; John D. Taggart, Secretary. Attendance 29.

Lafayette.—September 29, 1923. William Welsh, president of the Branch, spoke on his summer's work with the Pennsylvania Power & Light Co.

October 6, 1923. A motion picture, "The King of the Rails," loaned by the General Electric Company, was shown.

October 13, 1923. "Electrification of Railroads," was discussed by the students, with reference to the Chicago, Milwaukee & St. Paul, New York Central, Norfolk & Western, New York, New Haven & Hartford.

October 18, 1923. Members of this branch attended a meeting of the Lehigh Valley Section in the Easton Public Library, where H. K. Smith, of the Westinghouse Electric & Mfg. Co., spoke on "Electrification of Railroads." Attendance 19.

Lehigh University.—November 1, 1923. A business meeting preceded the presentation of papers "Prime Movers at the Bethlehem Steel Co." by Mr. Wrenberg, and "The Electrical Engineer in the Steel Industry," by D. M. Petty. Attendance 62.

University of Maine.—November 5, 1923. Election of officers; H. L. Kelley, President; G. E. Saunders, Vice-president; C. M. Sinnett, Treasurer; H. E. Bragg, Secretary. Attendance 21.

Marquette University.—October 11, 1923. Subject: "The New Radio Microphone Transmitter," by J. B. Kramer. Prof. Kartak explained the new relay handbook to be published by the A. I. E. E. and the N. E. L. A. Attendance 45.

November 8, 1923. Business meeting. Attendance 9.

School of Engineering of Milwaukee.—October 9, 1923. Election of officers as follows: I. L. Illing, Chairman; J. M. Ambrose, Vice-Chairman; A. U. Stearns, Secretary; E. C. Freshwaters, Treasurer. The papers presented were: "The Bradleystat, Bradleyleak and Bradleyometer," by R. T. Hatchett; "Qualities to be Gained during College Days", by F. P. Kasparek; "The Field of Modern Illumination," by I. L. Illing; "Telephone Communication," by H. C. Groth. Attendance 38.

University of Missouri.—October 22, 1923. Talks on summer experiences by students, M. V. Maxwell, B. E. Fuqua, B. A. Fisher, S. P. O'Bannon. Attendance 63.

November 5, 1923. Subject: "Mazda Lamp and Radio Tube Manufacture." Speaker: L. Sprangen. Attendance 50.

Montana State College.—October 30, 1923. Lecture by C. M. Sloan, District Engineer, C. M. & St. P. Ry. Attendance 70.

November 6, 1923. Paper on "Power Development," by senior engineering students. Attendance 96.

University of Nebraska.—November 1, 1923. Prof. W. F. Norris spoke on "Lightning Arresters." Attendance 42.

University of North Carolina.—October 22, 1923. Business meeting, followed by talk on "Cooperative Work, and the Dangers of Suppressed Low-Voltage Transmission Lines," by F. B. Smiley. G. G. Matteson gave a talk on "The Colfax Plant at Pittsburgh." Attendance 53.

November 11, 1923. Talks on "Cooperative Work" by O. L. Girsch and "Application of Automatic Substations to Coal Mining." Attendance 40.

University of North Dakota.—October 8, 1923. Business meeting and talk by Prof. Jenkins on the "Purpose and Work of the Student Branch of the A. I. E. E." Attendance 23.

October 22, 1923. Subject: "University Broadcasting Station." Speaker: James Lamb, of the Electrical Construction Co., Grand Forks, N. D. Attendance 23.

Notre Dame University.—October 15, 1923. There was a short talk, following a business meeting, on "The Theory of the Reversing Motor," and a demonstration followed. Attendance 51.

November 5, 1923. Business meeting and talk by Mr. Northcott on "Graduate Courses for Engineers." Attendance 61.

Ohio Northern University.—October 18, 1923. Subjects: "Third Brush Control on Automobile Generators," by Mr. Upp; "Electrification of Railways," by Mr. Smith; Dean Alden gave a criticism of the preceding talks. Attendance 37.

November 1, 1923. This meeting was a smoker. Two papers were given: "Reverse Current Relays as Used on Power Stations," by Mr. Beyer, and "Electrical Equipment on Aeroplanes," by Mr. Orton. Attendance 47.

Ohio State University.—November 2, 1923. Business meeting. Attendance 15.

Oklahoma A. & M.—October 26, 1923. Business meeting, followed by an address by Mr. Mitschrich on "Transformers." Attendance 42.

University of Oklahoma.—October 18, 1923. Election of officers; R. B. Greene, President; H. C. Schaeffer, Vice-president. Short talks by professors on their summer work. Attendance 18.

Oregon State Agricultural College.—October 24, 1923. Business and social meeting. Attendance 100.

University of Pittsburgh.—September 28, 1923. Election of officers as follows: G. H. Campbell, Chairman; W. T. Pyle, Vice-chairman; F. Wills, Secretary-Treasurer. Attendance 37.

October 12, 1923. Subject: "Merits, Advantages, History, and Statistics of the A. I. E. E." Attendance 35.

Purdue University.—October 30, 1923. Subject: "Utility Financing and Its Relation to Engineering." Speaker: B. H. Gardner, Northern Gas and Electric Company. Attendance 34.

Rensselaer.—October 9, 1923. Subject: "Some Phases of Engineering in the Telephone Industry." Speaker: H. L. Davis, of the New York Telephone Co. Attendance 175.

Rutgers.—October 25, 1923. Business meeting. Attendance 16.

University of Southern California.—October 23, 1923. Business meeting. Attendance 12.

November 1, 1923. Business meeting, and talk by Prof. Biegler on the A. I. E. E. and engineering students. Attendance 50.

Stanford University.—October 16, 1923. Subject: "Institute Aims and Activities." Speaker: H. H. Henline. Attendance 15.

October 30, 1923. Prof. Harris J. Ryan talked on "The Origin of A. I. E. E. Student Branches," and "Charles Proteus Steinmetz." Attendance 30.

Swarthmore College.—October 5, 1923. Business meeting and election of officers as follows: Albert L. Williams, President; Spencer R. Keare, Secretary.

October 12, 1923. Subject: "Manufacture of Paper." Speaker: Dr. Fussell.

October 19, 1923. Subject: "Description of the Operation of the Telephone." Speaker: Albert Williams.

October 26, 1923. Sumner Oliver gave a talk on his summer work with the Philadelphia Electric Co.

Syracuse University.—September 26, 1923. Subject: "Nela Park, its Organization and Operation." Speakers: J. G. Hummel and E. J. Agnew. Attendance 21.

October 3, 1923. Subject: "Students' Six Weeks Summer Course with the N. Y. Telephone Co." Speaker: L. D. Wacker. Attendance 18.

October 10, 1923. Subject: "Experiences with the Meter Testing Dept. of the Syracuse Lighting Co." Speakers: G. E. Tenant and B. P. Greenleaf. Attendance 16.

October 15, 1923. Subject: "Reminiscences of the Organization of the A. I. E. E. in the College of Applied Science." Speaker: Vice Chancellor William P. Graham. Luncheon was served. Attendance 29.

October 17, 1923. Subjects: "The Story of Frequency," by T. J. Rogers, and "The Metallic Sodium Vacuum Tube," by A. F. Burns. Attendance 20.

October 24, 1923. Subjects: "Water Power Development in the Upper Hudson," by J. Kenneth Savage, and "Experiences in Hotel Maintenance," by H. J. Hall. Attendance 21.

October 31, 1923. Subjects: "The History of the Induction Motor," by C. F. Bowman, and "An Engineering Problem," by E. H. Filsinger. Attendance 20.

Virginia Polytechnic Institute.—October 17, 1923. Election of officers: T. L. McClung, Chairman; E. M. Melton, Secretary and Treasurer. Attendance 31.

University of Virginia.—October 9, 1923. Business meeting and talk by Prof. W. S. Rodman on "Opportunities for a Broader Engineering Education." Attendance 22.

Washington State College.—October 15, 1923. Subjects: "The Relation of the A. I. E. E. to the Students and the Benefit They Might Derive from It," by Dean H. V. Carpenter; "The Electrification of Battleships," by Prof. Sloan; and "Selling Yourself," by Prof. Snyder. Attendance 135.

University of Washington.—October 16, 1923. Subject: "Engineering Colleges and the Institute," by Dr. Magnusson. Attendance 32.

November 6, 1923. Subject: "Voltage Transformers," by L. B. Robinson, of the General Electric Company. Attendance 35.

West Virginia University.—October 22, 1923. Subjects: "Utilization of By-Products from Steel Plants," by S. R. Hall; "Japanese Engineering and Structures," by J. S. Copley; and "Life of George Westinghouse," by C. E. Hutchinson; "Alinement of Steam Turbine Bearings," by W. F. Steel; "Building of Turbo Alternator Coils," by A. Chabamel; "Automatic Reclosing Circuit Breakers," by R. Lee; "Care of Power Transformers," by G. C. Pugh. Attendance 25.

November 5, 1923. Subjects: "Waterproofing of Cloth by Electro-Chemical Process," by Reynolds; "The Life of Charles P. Steinmetz," by M. C. Holmes; "High Steam Pressure," by I. A. Pitsenberger; "Available Water Power in West Virginia," by F. W. Gramm; "Electrical Development in Australia," by E. C. Jones; "Biography of George Westinghouse," by R. C. Crush; "State Responsibility of Water Power," by N. W. Naylor; "Development of Superpower," by M. L. Henderson; "Electrification of Railways," by A. G. Kisner; "Inspection and Testing of Alternators," by A. A. Winter; "History of Electric Lighting," by K. M. Wolfe. Attendance 34.

University of Wisconsin.—October 24, 1923. Business meeting. Attendance 16.

PERSONAL MENTION

John E. Magnusson has become assistant to the Electrical Engineer, Phoenix Utility Co., Duluth, Minn.

W. M. Harbaugh has recently formed a connection with the Lehigh Portland Cement Co., Mason City, Iowa.

David Sonkin has recently become affiliated with F. A. D. Andrea, Inc., New York City, as Radio Engineer.

P. L. Berton has resigned from the employ of the Western Electric Co. in order to study divinity at Washotah House, Washotah, Wis.

Ernest B. Millar has changed his connection from the English Electric Co. of Australia to The Electrical Plant Manufacturers, Ltd., N. S. W., Australia.

A. W. Pride has recently been transferred from Derry, Pa. to Emeryville, Cal., in charge of a new Porcelain Section, Division Office of the Westinghouse Elec. & Mfg. Co.

Harry H. Craiglow announces that he became associated, on November 1 with the D. A. Ebinger Sanitary Manufacturing Co., of Columbus, Ohio, in charge of operation.

Louis H. Hyde, who has been employed with the General Electric Co. for the last four years, has accepted a position as Power Engineer for the Western Electric Co., Cicero, Ill.

G. Ross Henninger has left the Supply Engineering Dept. of the Westinghouse Elec. & Mfg. Co. to become Protection Engineer for the Southern California Edison Co., Los Angeles, Cal.

David C. Rankin has severed his connection with the Ballantine Electrical Co. of Chicago, Ill. to take a position with the Commonwealth Power Equipment Co. of Melbourne, Australia.

Chas. E. Glassner has recently become Sales Engineer for the National Carbon Co., 237 E. 41st St., New York City. He resigned from the employ of the General Electric Co. on July 15th.

H. C. Forrest has accepted a position at the University of Virginia, Department of Electrical Engineering, having resigned as draftsman for the American Locomotive Co., Schenectady, N. Y.

Chas. S. Dawson, until June 1st, Commercial Engineer with the Scranton Electric Co., on that date resigned to become manager of the West Virginia Water & Electric Co. at Charleston, W. Va.

Frank M. Kirby, formerly Superintendent and Estimator of the Edwards Electrical Construction Co., has become a member of the firm Kirby-Hellman, with offices at 145 W. 41st St., New York, N. Y.

Martin P. Rice became on December 1st Manager of the Publicity Department of the General Electric Company. This department is a combination of the Publication and Advertising Departments.

John H. Donohue, has recently left the employ of the Foundation Company and has joined Abbott Merkt & Co. as Electrical Superintendent on the Paterson Parchment Paper Company's new plant at Edgely, Pa.

W. J. Anglemyer has severed his connection with the Kellogg Switchboard and Supply Co. of Chicago, where he was Research Engineer, to accept a position as Manager of the Tri-City Auto Laundry, in Santa Monica, Cal.

Alexander Nyman, formerly engaged in engineering development work at the Westinghouse Elec. & Mfg. Co. has accepted the position as Director of Engineering with the Dublier Condenser and Radio Corp., New York, N. Y.

R. R. Knoerr has severed his connection with the Generator Design Department of the General Electric Co., at Lynn, Mass. and is now engaged in electrical contracting with the firm of Knoerr & Fischer in Milwaukee, Wis.

Edward T. Anderson, whose former connection was Electrical Engineer for Smith, Hinchman & Grylls of Detroit, Mich., now holds the same position with the Board of Water and Electric Light Commissioners of Lansing, Mich.

J. Harrison Belknap formerly assistant professor of Electrical Engineering, Oregon State Agricultural College has accepted a position in the Control Engineering Division, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

S. G. Gassaway, Field Superintendent in charge of operations in Oklahoma for the Lone Star Gas Co., has resigned that position to join the Byllesby organization as Asst. Commercial Manager of the Oklahoma Gas & Electric Co.

Frank H. Gale, who for the past seventeen years has been in charge of the space advertising of the General Electric Company, has been assigned to the staff of Dana R. Bullen, whose new position is referred to elsewhere in this issue.

A. G. Steinmayer has resigned his position as Asst. Chief Engineer with the Electrical Engineers Equipment Co., of Chicago, Ill. and accepted a position as Electrical Engineer with the Line Material Co. of South Milwaukee, Wis.

Newton Jackson, at present located in Newport, R. I., where he is serving in an advisory capacity to the Newport Electric Corp., has recently accepted a position as a member of the engineering staff of Sanderson & Porter, New York, N. Y.

Dana R. Bullen, for a number of years manager of the Supply Department of the General Electric Co., Schenectady, N. Y., has been advanced to the position of Asst. Vice-President on the staff of the Vice-President in charge of sales of general apparatus and supplies.

David C. Hopper, who for the past four years was connected with the Northern Ohio Traction & Light Co., as Distribution Engineer, has resigned to accept a position with the Duquesne Light & Power Co., Pittsburgh, Pa. as Asst. to the General Superintendent of Distribution.

H. L. Unland, for thirteen years engineer with the General Electric Company, eleven years of which were spent in the Power and Mining Dept., of the General Electric Co., leaves that concern December 1st, to take the position of Electrical Engineer with the Victor Talking Machine Company, Camden, N. J.

Robert A. Millikan, of the California Institute of Technology, recently awarded the Edison Medal, has since been awarded the Nobel Prize for Physics, also the Hughes medal by the Royal Society of London in recognition of his determination of the electronic charge and other physical constants.

Percy H. Thomas will resume his practise as a Consulting Engineer on January 1, 1924. As Consulting Electrical Engineer for Guggenheim Bros. he has had charge for some years past of the Power Department of their engineering organization, which has developed the well-known copper properties of that firm in Chile. Previous to this work Mr. Thomas had a consulting practise in New York City, to which he is now returning.

Vladimir Karapetoff of the School of Electrical Engineering, Cornell University, has been awarded a prize of four thousand francs by the Montefiore Foundation of the University of Liege, Belgium. The award was made for his kinematic computation devices of electrical machinery, described in the technical press during the last three years. A committee of five Belgians and five foreign members, which makes these awards, has characterized this work as an expression of a "new idea which may lead to important developments in the domain of electricity."

Obituary

CLINTON H. TURNER died on October 21, 1923 at North Reading, Mass. He was a graduate of Wentworth Institute and the Eastern Radio Institute, both in Boston, Mass. He became an Associate of the Institute in 1922.

ALBERT R. LEDOUX, President of Ledoux & Co., Inc., Consulting Engineers of New York City, died on October 14, 1923 as the result of influenza. Dr. Ledoux became an Associate of the Institute in 1886.

P. N. JONES, General Manager for Receivers of the Pittsburgh Railways Co., died on July 1, 1923. At the time he became an Associate of the Institute, in 1904, he was manager of the Cleveland office of the Westinghouse Electric & Mfg. Co. He was born and educated in Ohio, having graduated from Ohio State University in 1892.

JOHN ELY MOORE, Plant Engineer of Methods of the Western Electric Company, Hawthorne Station, Chicago, Ill., died on October 10, 1923. He was a graduate of Purdue, receiving the degree of M. E., and he held the degree of E. E. from Princeton University. For five years he was an instructor in Electrical Engineering at Princeton University. The large part of his electrical work was in the design and construction of power plants and transmission systems for industrial plants. He became an Associate of the Institute in 1908 and a Member in 1913.

GEORGE A. CELLAR, formerly General Superintendent of Telegraph of the Pennsylvania Railroad system, died in Philadelphia, November 13, 1923. He had been continuously in the service of the Pennsylvania system for more than forty-six years, having started as telegraph operator and clerk in 1877. He was born in Ohio in 1860 and received his education in that state. He was closely associated with several of the national organizations in the telegraph and telephone field, Mr. Cellar became an Associate of the Institute in 1911 and was transferred to Membership in 1921.

Employment Service

The Engineering Societies Employment Service is conducted by the national societies of Civil, Mining, Mechanical, and Electrical Engineers as a cooperative bureau available to their membership, and maintained by the joint contributions of the societies and their individual members who are directly benefited.

MEN AVAILABLE.—Under this heading brief announcements will be published without charge to the members. These announcements will not be repeated, except upon request received after an interval of three months, during which period names and records will remain in the active files of the bureau. Employers are referred to previous issues of the Journal. Notice for the JOURNAL should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City.*** *Such notices will not be acknowledged by personal letter, but if received prior to the 16th of the month will usually appear in the issue of the following month.*

OPPORTUNITIES.—A bulletin of engineering positions available will be published and will be available to members of the societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the societies in the financing of the work by nominal contributions. It is believed that a successful service can be developed if these contributions average $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum. temporary positions (of one month or less), three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will, it is hoped, be sufficient to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled, will not be forwarded.

MEN AVAILABLE

ELECTRICAL AND HYDRAULIC ENGINEER or resident manager, domestic or foreign. Age 45; single; graduate degree PHB in E. E. Yale. 25 years in field, 14 years as construction engineer, department sales manager, sales manager, export engineer; salesman for Westinghouse. 11 years on Pacific coast as chief engineer in charge of design, construction and operation four hydraulic power systems, 25,000-66,000 volts. Major U. S. A. A. E. F. 18 months in France, chief electric officer. At present consulting work in Alaska and Northwest. E-4552.

ELECTRICAL ENGINEER, recent graduate B. S., E. E., desires position with manufacturing or consulting company offering an opportunity in power designing to one showing initiative and analytical ability. One year experience in executive work. Enrolled Student A. I. E. E. Assoc. A. R. E. Age 24. E-4553.

EXECUTIVE SALES ENGINEER. Technical graduate desires connection in sales department of progressive manufacturing concern located in middle west. Twelve years' experience in executive and sales work with large electrical manufacturer. E-4554.

ELECTRICAL ENGINEER with B. E. E. and M. S. C. Degree. Age 31; married; 3 years G. E. Co., test and 4 years' general experience covering installation, operation and maintenance of electrical equipment including power plants, power lines, substation. Can organize and handle men. Student of Alex. Hamilton Institute. Excellent references. Midwest preferred. E-4555.

GRADUATE ELECTRICAL ENGINEER. Assoc. M. A. I. E. E. with three years' experience in instrument and transformer work. Thorough knowledge of instrument, transformer, relays shunts. Desires position with a manufacturing consulting or sales organization. E-4556.

ELECTRICAL ENGINEER, age 35; married. Fourteen years' experience power plant and substations design and construction. General engineering, including hydro-power plants, steam stations, industrial plants, etc. Can handle men and have executive ability. Prefer position as assistant to an executive, but will consider any offer with permanency and chance for early advancement. Minimum salary $3600. Available on one month's notice. E-4557.

SALES AGENT wishes to represent an electrical manufacturer in conjunction with present radio line. Travels Minnesota, Wisconsin, Indiana and Illinois with offices in Chicago. Selling jobbers only at present. Graduate E. E. Assoc. A. I. E. E. and I. R. E. E-4558.

M. I. T. GRADUATE 1922 E. E., now working at sales promotion and power service installation in large public utility would like position in sales, commercial or business work where technical training would be of use. E-4559.

ELECTRICAL ENGINEER, seven years' teaching experience in engineering school. Nine years' engineering experience both office and field in responsible charge of design and installation of high-tension substations and underground transmission. Wishes to locate with central station company or consulting engineers doing engineering work of this character. E-4560.

YOUNG MAN, age 25; single. University graduate in E. E., one year experience in sales office drafting, sugar mill electrification, and with public utility on reconstruction and plant betterment work, desires position with public utility or with technical institution where graduate work can be carried. Speaks two foreign languages. Either commercial or technical position accepted anywhere except the south. E-4561.

SALES ENGINEER OR ASSISTANT TO EXECUTIVE. Graduate in E. E. and M. E. with ten years' specialty sales experience covering both field selling and office routine. Have handled electrical and mechanical devices. Also branch office manager for large storage battery manufacturer. E-4562.

CENTRAL STATION EXECUTIVE, experienced in every branch of electric public utility; engineering, operation, construction, sales and management. Desires position as division superintendent or commercial engineer Technical graduate. E-4563.

ELECTRICAL ENGINEER, Assoc. A. I. E. E., B. S. degree in electrical engineer, 4 years' experience in the design of a-c. substations, one year of which I was in charge of the drafting room, and also in the preparation of specifications for substation equipment. At present employed, but would like to make change for good reason. Can furnish references. E-4564.

TECHNICAL GRADUATE with degree of B. S. in E. E. 1922. One year practical electric work and one year as price estimator with electrical manufacturing concern. Desire electric railway or power work. Location preferably south or southwest. Age 24; single. E-4565.

ELECTRICAL AND MECHANICAL ENGINEER experience in all branches of electric light and power work. Columbia graduate with twelve

years' experience in mechanical and electrical central station practise, including design and construction of overhead and underground transmission and distribution systems, relay protection and automatic substations. At present employed by a large public utility in responsible position but desirous of making change to locate in New York City. Licensed professional engineer, New York State. E-4566.

ELECTRICAL ENGINEER. Twelve years' central station experience, familiar with rates, with ten years' supervisory experience, desires managerial opportunity, preferably with small utility. E-4567.

RESEARCH 1908 graduate electrical and mechanical engineer, desires position where his ability in physics and higher mathematics would be applied to best advantage. 12 years' experience in electric machine design (a-c.) and electric furnace problems. Speaks fluently English, French, German. E-4568.

ENGINEER DESIGN AND DEVELOPMENT, technical training and five years' of experience in testing and development work on electrical and mechanical apparatus with the engineering department of a large concern. Have done considerable testing of metals and electrical insulation materials used on a wide range of apparatus. Desire responsible position with any concern offering opportunity. New York or vicinity desired. E-4569.

JUNIOR SALES ENGINEER technical or executive assistant, age 27, desires a position with a reliable concern. E. E. Graduate. Have five years' of varied technical experience, and also sales experience. Graduate of business administration course. Initial salary secondary. Just a position with a fighting chance. E-4570.

ELECTRICAL CONSTRUCTION AND MAINTENANCE FOREMAN wishes position with some established manufacturing concern or public utility company. 11 years' experience. 3 years' in service shop and road. 3 years G. E. test. Technical education. Best of references. Married; age 33. E-4571.

CEMENT MILL ENGINEER, age 29; at present employed by a large cement company. Technical graduate, experienced in design of new plants and additions and improvements to existing structures, waste heat installations, etc. Desires position as chief draftsman or designing engineer. Salary expected $400. per month. E-4572.

ELECTRICAL-MECHANICAL ENGINEER, 6 years' varied experience hydroelectric power plant operation, Pelton, Francis, Allis-Chalmers, Mortan Smith wheels and governors synchronous convertors, rotary convertors, 3 years inside and outside wiring substations, power plants and concentrators. Desires responsible position. Can handle men; speaks Spanish; married; age 32. E-4573.

UNIVERSITY GRADUATE IN ELECTRICAL ENGINEERING, age 25, with two years' experience with a manufacturing concern and now in charge of the operation and maintenance of large battery installations in territory. Would like to be connected with a manufacturing or consulting firm doing work in electric railway or power transmission and offering opportunity for advancement. Location, Eastern States preferred. E-4574.

ELECTRICAL ENGINEER would like to connect with an electric power company, on maintenance and repair or construction work. Am experienced on meter testing and installing switchboards, also on general construction work. I have had two years' test floor experience at the Westinghouse shops. E-4575.

GRADUATE ELECTRICAL ENGINEER, seven and a half years' experience on engineering of power plants, substations, distribution and transmission systems for large power companies. Now desires position with progressive utility. Now employed as distribution engineer. Desires permanent position only. E-4576.

TECHNICAL GRADUATE, 11 years' experience including power plant layout, installation and supervision of operation and layout of distribution networks, desires permanent employment with public utility company. Location immaterial. E-4577.

ELECTRIC UTILITY MAN, graduate engineer with 5 years' varied experience in transmission line and distribution construction, some underground, maintenance, operating and commercial departments; have successfully negotiated municipal contracts and large power sales. Desire position as assistant to superintendent or as power engineer with an electric utility in New England; age 28; married. Assoc. A. I. E. E. Available December 1st. E-4578.

ELECTRICAL ENGINEER, University graduate, Mem. A. I. E. E., with 3 years' experience in railroad electrification, office and field work; 4½ years mechanical railroad experience. Desires position with big contracting firm in construction of power-plants or etc., railway engineering. Knowledge of four languages; age 27; married. Location desired N. Y. C. E-4579.

METALLURGIST. M. I. T. graduate. Age 26; 3 years' experience manufacturing parts for electrical equipment, including sheet steel, iron steel, copper, brass and aluminum castings. Problems in the hardening shop, machine shop, firebrick plant, routing production, rate setting, cost accounting. E-4580.

ELECTRICAL ENGINEER B. S. from M. I. T. in 1922; age 24; single. G. E. test experience and a year of public utility work. Desires position with a small growing concern as executive's assistant along public utility lines. Preferably New England, other locations considered. A. I. E. E. Assoc. E-4581.

GRADUATE ENGINEER M. E., E. E. Cornell, Assoc. A. I. E. E., age 31 years; single; location immaterial. 2 years' assistant to chief engineer drafting and plant testing, 6 years electrician, assistant chief engineer, acting chief engineer construction, operation, maintenance, mechanical and electrical divisions electrified sugar factories Cuba and Porto Rico. 1 year Com. Officer steam engineers Div. U. S. N. Desires position with construction, power or consulting engineer. E-4582.

ELECTRICAL ENGINEER AND EXECUTIVE, 43; married; technical education; Assoc. A. I. E. E. 28 years' unusually broad experience in every conceivable phase involved under the heading of "electrical machinery." Thorough experience in design and production from fractional to 300 kw., experienced in application, sales. and maintenance, industrial and power plant design and installation. Business and factory management of large repair shop and rebuilt machinery. Wants connection with good organization at reasonable salary. E-4583.

SALES ENGINEER M. I. T., 1918. Open for a larger opportunity. Sales experience, electrical. Prior engineering experience, marine steam power plants. For past year in supervisory sales engineering capacity for large electrical manufacturer. E-4584.

ELECTRICAL ENGINEER, Mem. A. I. E.E., licensed engineer, N. Y. State, have 25 years' in office, shop, power stations and high-tension lines, design construction and operation. Last 7 years engineer for large industrial, three plants, electric furnaces 25,000 kv-a. Previous with hydroelectric stations positions as superintendent 80,000 h. p. rotary stations 45,000 kv-a. Will accept agency for equipment in Western N. Y. E-4585.

YOUNG MAN 5 years' electrical experience. Westinghouse student course and engineering school; experience with large manufacturing company in equipping of electric railroads, and with a public utility company. Desires a position with an electric railway, manufacturing concern or public utility. E-4586.

ELECTRIC ENGINEER, young technical graduate, single. Has had experience in testing, wiring, maintenance and power plant work, particularly in the transformer end. Desires connection with public utility or on construction work. Location immaterial. Available on short notice. E-4587.

SALES AND EXECUTIVE ENGINEER, with thirteen years' domestic and foreign experience in manufacture, engineering and business development of transmission material. At present employed, seeks position of greater responsibility and activity. E-4588.

ELECTRICAL ENGINEER, technical graduate, four years' experience designing steam and electric machinery, power plant design. Desires position as chief engineer power plant or with engineering firm. E-4589.

ELECTRICAL AND MECHANICAL ENGINEER, technical graduate, 32; eight years' experience in industrial and power plant design and construction and purchasing, desires permanent connection in engineering or sales position. Will consider any good proposition. E-4590.

ELECTRICAL ENGINEER, age 33; technical graduate; professional license; 14 years' experience covering master electrician, foreman superintendent, designer, draftsman, estimator, construction engineer, inspector, sales engineer, executive engineer. Desires position with reliable concern. E-4591.

GRADUATE ELECTRICAL ENGINEER, 24 years of age; 9 months' experience shell manufacturing, two months' experience small motor tests, sixteen months' experience switchboard design and responsible charge of drafting, wiring and factory assembly. Now employed. Desires change of location with future for executive work and application of originality. E-4592.

PUBLIC UTILITY ENGINEER 30 years' electrical railway, light, power, gas, charge of design, plants, equipment, purchase, appraisal. Prefer executive, coordinating or publicity position. E-4593.

GRADUATE ELECTRICAL ENGINEER, Assoc. A. I. E. E., Asst. City & Guilds Engineering College, London; age 34, with 13 years' experience in design, construction and operation of power stations and substations for light, power and traction systems, reports, specifications contracts, desires opportunity for position with an electric railway, public utility or consulting engineer. References given if desired. Knowledge of French, German, Italian and some Spanish. Moderate salary. Location immaterial. Would accept field work. E-4594.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER, Technical training from France and Switzerland; age 34; single; 8 years' varied experience in Europe and the United States, designer of power stations and substations, foreman of electric railway, repair shop and estimating engineer. Desires a position as power station designer. Location, New York City. E-4595.

STEEL MILL ELECTRICAL ENGINEER, wants position. Technical graduate; 32 years of age, factory, operation and construction experience. Quite familiar with control of steel mill equipment. E-4596.

CIVIL SERVICE POSITIONS

JUNIOR METALLURGIST, must be graduate, B. S. degree from recognized college, having majored in metallurgy. Special credit for experience in metallurgy or graduate work therein. Research work in gold and silver metallurgy desirable. Salary $1500-$2000.

ASSOCIATE PETROLEUM ENGINEER for vacancy in Bureau of Mines, for duty at Bartlesville, Okla., work consisting of investigation in Kansas oil fields with reference to application of cementing operations for the exclusion of water from wells. Salary $3000.

ASSISTANT ENGINEER. Applicant must be examined in one of the following subjects: Chemical engineering, civil engineering, electrical engineering, electrochemistry, general chemistry or mechanical engineering, and must have knowledge of French or German. Salary $1500 per annum and $240 bonus.

Full information as to date of examination and application blanks may be had by addressing U. S. Civil Service Commission, Washington, D. C.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held November 19, 1923, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

ALLEN, OLIVER F., Commercial Engineer, International General Electric Co., Schenectady, N. Y.

STICKNEY, GEORGE H., Illuminating Engineering Asst. to Sales Manager, Edison Lamp Works of General Electric Co., Harrison, N. J.

To Grade of Member

BURLINGHAM, CHARLES S., Jr., Business Research Engineer, West Penn Railways Co., Pittsburgh, Pa.

RALSTON, FARLEY C., Research Engineer, Philadelphia Electric Co., Philadelphia, Pa.

TODD, ROBERT I., President and General Manager, Indianapolis Street Railway Co., Indianapolis, Ind.

TOLMAN, CHARLES P., Consulting Engineer, New York, N. Y.

ASSOCIATES ELECTED NOVEMBER 23, 1923

AJAINI, FRANCESCO, General Manager, Societa Italiana Telefoni Privati, Via Pietro Calvi, 31, Milan, Italy.

EVANS, CLIVE WALKER, Electrical Engineer, Mount Bischoff Tin Mining Co., Waratah, Tasmania.

HUNTSBERGER, JOHN DONALD, Specification Clerk, Bell Telephone Co. of Pa., 261 N. Broad St., Philadelphia; res., W. Philadelphia, Pa.

McLAREN, WESLEY E., Superintendent, Electrical Dept., United Fruit Co., Bocas del Toro, Panama.

MENSCHIK, IRVING, Assembler, Mica Condensers, Dubilier Radio Corp., 48 West 4th St., New York, N. Y.

OSTROFF, LOUIS, Electrical Designer, T. E. Murray, Inc., 55 Duane St., New York, N. Y.

SAKI, TOSSY, Armature Winder, Utah Copper Co., Arthur Plant, Garfield; res., Salt Lake City, Utah.

TIGERSTEDT, E. M. C., Electrical Engineer, 337 Riverside Drive, New York, N. Y.

TURNPAUGH, WALTER SCOTT, Manager, Beckett Electric Co., Banco Mercantile Bldg., Monterrey, N. L., Mex.

VERE, FERNAND, P. O. Box 216, San Juan, P. R.

Total 10

ASSOCIATES REELECTED NOVEMBER 23, 1923

BOURLON, ALFRED, Electrical Engineer, Hubard & Bourlon, Apartado 1194, Mexico, D. F., Mex.

LENNOX, JOHN S., Electrical Engineer, Transformer Dept., General Electric Co., Pittsfield, Mass.

SEYMOUR, EARL R., Sales Engineer, General Electric Co., Schenectady, N. Y.

MEMBERS ELECTED NOVEMBER 23, 1923

CUSHING, RAYMOND G., Electrical Engineer, Stone & Webster, Inc., 147 Milk St., Boston; res., Stoughton, Mass.

MULLER, RICHARD FREDERIC ANTOINE, Technical Writer, 1474 Columbia Road, Washington, D. C.

TRANSFERRED TO GRADE OF FELLOW, NOVEMBER 23, 1923

BUCK, A. MORRIS, Associate Editor, Electric Railway Journal, McGraw-Hill Company, 10th Avenue and 36th Street, New York, N. Y.

GRAHAM, WILLIAM P., Vice-Chancellor, Syracuse University, Syracuse, N. Y.

PARKS, CHARLES WELLMAN, Rear Admiral (C. E. C.) U. S. Navy, Retired.

TRANSFERRED TO GRADE OF MEMBER NOVEMBER 23, 1923

HARTLEY, R. V. L., Telephone Engineer, Western Electric Company, 463 West Street, New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before October 31, 1923.

Abbott, W. F., General Electric Co., W. Lynn, Mass.
Abell, R. A., Western Electric Co., New York, N. Y.
Adams, R. M., Pennie, Davis, Marvin & Edmonds, New York, N. Y.
Agins, G., Electrical Testing Laboratories, New York, N. Y.
Anders, R. H., Indiana & Michigan Electric Co., South Bend, Ind.
Ashley, H., Stanford University, Palo Alto, Calif.
Aspin, N., Price Bros. & Co., Chuto-aux-Galets, Chicontime, P. Q.
Austin, F. D., Durant Motors of Canada, Ltd., Leaside, Ont., Can.
Bacon, T. S., General Electric Co., New York, N. Y.
Bailey, J. C., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Bailey, S. S., Commonwealth Edison Co., Chicago, Ill.
Baker, R. H., Westinghouse Elec. & Mfg. Co., Syracuse, N. Y.
Balcke, W. H., Stone & Webster, Inc., Boston, Mass.
Baldwin, J. F., Philadelphia Electric Co., Philadelphia, Pa.
Bartholomew, G. W., Industrial Elec. Service of Erie, Erie, Pa.
Bechoff, F. N., Radio Corp. of America, New York, N. Y.
Beebe, H. M., The Eastern Connecticut Power Co., Uncasville, Conn.
Beers, R. S., General Electric Co., Schenectady, N. Y.
Benson, U. J., McCall Publishing Co., New York, N. Y.
Bergvall, R. C., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Biavati, J. D., Cutler-Hammer Mfg. Co., New York, N. Y.
Black, H. B., Harrisburg Mechanical School, Harrisburg, Pa.
Blair, J. S., Bell Telephone Co. of Pa., Philadelphia, Pa.
Blenden, W. L., Southwestern Bell Telephone Co., St. Louis, Mo.
Boehm, A., Westinghouse Lamp Co., New York, N. Y.
Bonell, R. K., American Tel. & Tel. Co., New York, N. Y.
Bottger, R. E., Eagle Ottawa Leather Co., Grand Haven, Mich.
Bourgeois, C. H., Haughton Elevator Co., Toledo, Ohio.
Bradbury, W. H., (Member), Kingston Coal Co., Kingston, Pa.
Bries, M. M., D. P. Robinson & Co., Pittsburgh, Pa.
Brooks, L. R., General Electric Co., Erie, Pa.
Brown, L. R., (Member), General Electric Co., Pittsfield, Mass.
Brown, R. D., Pennsylvania Railroad System, Altoona, Pa.
Bryan, H. W., Union Switch & Signal Co., Swissvale, Pa.
Bugg, V. M., Western Electric Co., Inc., New York, N. Y.
Burchett, A. C., Jr., Aluminum Ore Co. of America, E. St. Louis, Ill.
Busey, P. G., Vice-Pres., Busey's State Bank, Urbana, Ill.
Butler, C. E., Westinghouse Elec. & Mfg. Co., Chicago, Ill.
Caddy, H. P., Karl Andren Co., Boston, Mass.
Casper, W. L., Western Electric Co., Inc., New York, N. Y.
Chisholm, H. E., Western Electric Co., Philadelphia, Pa.
Christie, J. S., J. S. Christie Elec. Test. Lab., Cleveland, Ohio
Clark, F. K., Broadway Corp., New York, N. Y.
Clark, L. F., Mass. Inst. of Technology, Cambridge, Mass.
Clason, R., Stevens & Wood, Inc., New York, N. Y.
Cotton, W. A., Jr., with C. E. Wise, Detroit, Mich.
Criley, W., Moore School of Elec. Engg., Univ. of Pa., Philadelphia, Pa.
Dambly, H. A., Philadelphia Electric Co., Philadelphia, Pa.
Danziger, H. S., Danziger-Jones, Inc., New York, N. Y.
Darche, A. T., Goodman Mfg. Co., Chicago, Ill.
Davidson, M. S., Western Steel Products Co., Denver, Colo.
Degen, F. I., (Member), Yosemite Lumber Co., Merced Falls, Calif.
Dengler, A. G., New York Tel. Co., Brooklyn, N. Y.
Dunn, M. L., Res. Engineer, L. T. Klauder, Williamsport, Pa.
Earle, R. T., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Ekeroth, W. M., Brooklyn Edison Co., Brooklyn, N. Y.
Ellestad, I. M., Northwestern Bell Tel. Co., Minneapolis, Minn.
Emerich, L. E., Leeds & Northrup, Philadelphia, Pa.
Faus, H. T., General Electric Co., W. Lynn, Mass.
Ferguson, C. V., General Electric Co., Schenectady, N. Y.
Ferrari, C., Consulting Engineer, New York, N. Y.
File, E. D., R. F. & P. Railroad, Potomac Yard, Potomac, Va.
Floyd, D. A., Public Service Electric Co., Trenton, N. J.
Frolich, F., Sanderson & Porter, New York, N. Y.
Galbraith, R. A. H., Lieut., Royal Corps of Signals, Ottawa, Can.
Gallagher, J. E., Brooklyn Edison Co., Brooklyn, N. Y.
Gault, J. S., University of Michigan, Ann Arbor, Mich.
Gedney, R., (Member), Tiffany & Co., Forest Hill, N. J.
Glass, H. J., Fairbanks, Morse & Co., New Orleans, La.

Gluck, J., 1709 Park Ave., New York, N. Y.
Goodison, A. M., Jr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Gorham, R. C., Cornell University, Ithaca, N. Y.
Graham, C. K., Springfield Light, Heat & Power Co., Springfield, Ohio.
Granger, H. I., Jackson & Moreland, Boston, Mass.
Greene, W. T., Northern New York Utilities, Inc., Watertown, N. Y.
Greenleaf, W. E., General Electric Co., W. Lynn, Mass.
Griffin, G. T., Bethlehem Steel Co., Sparrows Point, Md.
Gronquist, J. R., West Penn Power Co., Pittsburgh, Pa.
Gruber, G., Wm. Cramp & Sons, S. & E. B. Co., Philadelphia, Pa.
Guillemin, E. A., Mass. Inst. of Technology, Cambridge, Mass.
Gustason, C. F., Central Indiana Power Co., Indianapolis, Ind.
Guth, S.; res., 164 Sherman Ave., New York, N. Y.
Hall, C. A., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Hamilton, F. A., Jr., General Electric Co., Schenectady, N. Y.
Harl, G. P., University of Missouri, Columbia, Mo.
Havlick, J., Milwaukee Elec. Ry. & Light Co., Milwaukee, Wis.
Heck, J. H., Girard College, Philadelphia, Pa.
Hellman, M. P., Kirby & Hellman, New York, N. Y.
Herring, T. F., The Bristol Co., Pittsburgh, Pa.
Herzog, M. S., Stone & Webster, Boston, Mass.
Hopkins, J. W., Triangle Engineering Co., Zanesville, Ohio
Howell, E. H., General Electric Co., Ft. Wayne, Ind.
Howey, R., Lehigh Valley Coal Co., Centralia, Pa.
Hunt, S. S., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Inskip, L. S., Rensselaer Polytechnic Institute, Troy, N. Y.
Jelley, A. L., Nashua Mfg. Co., Nashua Mills, Nashua, N. H.
Jenner, Ed., Western Electric Co., Inc., Philadelphia, Pa.
Johnson, C. B., Commonwealth Edison Co., Chicago, Ill.
Jones, S. M., General Electric Co., Schenectady, N. Y.
Keller, C. C., Cleveland Elec. Illuminating Co., Cleveland, Ohio
Kendall, R. M., American Tel. & Tel. Co., New York, N. Y.
Kenyon, A. F., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Kersten, H. J., University of Wisconsin, Madison, Wis.
Ketcham, C. B., Westinghouse Elec. & Mfg. Co., Cincinnati, Ohio
Keys, N. L., School of Engg. of Milwaukee, Milwaukee, Wis.
King, M. E., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Kinghorn, A. H., Jr., Bell Telephone Co. of Pa., Philadelphia, Pa.
Klein, I., (Member), United Metal Box Co., Long Island City, N. Y.
Kositzky, J. C., Oklahoma A. & M. College, Stillwater, Okla.
Kreisher, C., Western Electric Co., Chicago, Ill.
Kutchera, A. J., (Member), A. J. Kutchera Co., Wilkes-Barre, Pa.
Kynor, M. W.; res., 454 Conover Terrace, Orange, N. J.
Labadie, E. F., Fisher Body Corp., Detroit, Mich.
Lampkin, C. A., Southern California Telephone Co., Hollywood, Calif.
Langford, J. A., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Lauritsen, C. C., Collin B. Kennedy Corp., St. Louis, Mo.
Lazich, B., Bell Telephone Co. of Pa., Pittsburgh, Pa.
Le Boutillier, C., Bell Tel. Co. of Pa., Philadelphia, Pa.
LeClair, T. G., Commonwealth Edison Co., Chicago, Ill.
Lee, B. W., General Electric Co., Schenectady, N. Y.
Leeven, A. A., New York Edison Co., New York, N. Y.
Leonard, J. D., New York Telephone Co., New York, N. Y.
Lindsley, F. M., Western Electric Co., Inc., Chicago, Ill.
Litchel, R. S., Philadelphia Electric Co., Philadelphia, Pa.
Looney, J. B., Westinghous Elec. & Mfg. Co., E. Pittsburgh, Pa.
Lucey, R. A., Central Aguirre Sugar Co., Central Aguirre, Porto Rico
Lutz, E. W., The Citizens Telephone Co., Circleville, Ohio
Malti, M. G., Cornell University, Ithaca, N. Y.
Marston, L. F., Detroit Edison Co., Detroit, Mich.
Mauran, J., Electric Storage Battery Co., Philadelphia, Pa.
McBerty, Mrs. Z. A., The Federal Machine & Welder Co., Warren, Ohio
McClellan, R. P., General Electric Co., Schenectady, N. Y.
McDowell, E. K., Donora Steel Works, Donora, Pa.
McHaffie, R. P., Winnipeg Electric Railway Co., Great Falls, Manitoba, Can.
McKinnon, D. A., Mexican Light & Power Co., Mexico City, D. F., Mex.
McNamee, B. F., Collin B. Kennedy Corp., St. Louis, Mo.
Meikle, G. S., G. S. Meikle Co., New York, N. Y.
Messinger, E., General Electric Co., Schenectady, N. Y.
Meyer, K. A., Lehigh Valley Coal Co., Wilkes-Barre, Pa.
Miller, C. K., Rochester Gas & Electric Corp., Rochester, N. Y.
Miller, E. K., Westinghouse Elec. & Mfg. Co., Huntington, W. Va.
Miller, G. L., Indiana Bell Telephone Co., Indianapolis, Ind.
Miller, J. B., Freed-Eismann Radio Corp., New York, N. Y.
Mimno, H. R., Rensselaer Polytechnic Inst., Troy, N. Y.
Mitchell, W. D., American Tel. & Tel. Co., New York, N. Y.
Moon, P. H., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Mooney, J., Jr., Pennsylvania Railroad, Philadelphia, Pa.
Moran, R. F., Hudson Coal Co., Scranton, Pa.
Morgenson, E. O., Perth Amboy Water Dept., Perth Amboy, N. J.
Morganson, M., Electric Bond & Share Co., New York, N. Y.
Morris, H. W., (Member), Treasury Dept., Washington, D. C.
Motley, J. G., Western Electric Co., New York, N. Y.
Muzzillo, M., New York Edison Co., New York, N. Y.
Nance, H. H., (Member), American Tel. & Tel. Co., New York, N. Y.
Neely, T., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Nels, Ed., Lehigh Portland Cement Co., Oglesby, Ill.
Neuberger, A. P., Public Service Production Co., Newark, N. J.
Nielsen, F., McClellan & Junkersfeld, New York, N. Y.
Niemann, W. J., Commonwealth Edison Co., Chicago, Ill.
Nygard, E., Western Electric Co., Inc., New York, N. Y.
Nyquist, H., (Member), American Tel. & Tel. Co., New York, N. Y.
Olivares, E., Electromotor Co., Coyoacan, D. F., Mex.
Pappageorge, N. G., Brooklyn Edison Co., Brooklyn, N. Y.
Parkins, C. L., Western Electric Co., New York, N. Y.
Peters, E. H., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Pollard, W. H., Fairbanks, Morse & Co., Indianapolis, Ind.
Polson, A. D., Tough Oakes Gold Mine, Kirkland Lake, Ontario, Can.
Poole, R. E., Stevens Institute of Technology, Hoboken, N. J.
Powell, T. W., Bureau of Pr. & Lt., City of Los Angeles, Los Angeles, Calif.
Race, H. H., Cornell University, Ithaca, N. Y.
Rauhe, C. H., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Reid, W. A., Public Service Electric Co., Paterson, N. J.
Remine, H. H., Detroit Edison Co., Port Huron, Mich.
Rhodes, E. D., Tolhurst Machine Works, Troy, N. Y.
Ring, L. L., Federal Light & Traction Co., New York, N. Y.
Rodgers, W. H., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Ronay, J., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Roper, M. L., (Member), Glen Alden Coal Co., Scranton, Pa.
Roth, J. W., Pennsylvania Railroad System, Altoona, Pa.
Royce, C. F., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Roys, C. S., General Electric Co., Schenectady, N. Y.
Ryder, B. H., (Member), American Steel & Wire Co., Chicago, Ill.
Schnyder, A., D. P. Robinson Co., New York, N. Y.
Schramm, R. F., Hudson Coal Co., Scranton, Pa.
Schultz, C. F., Cleveland Railway Co., Cleveland, Ohio
Schurch, E. C., General Electric Co., Kansas City, Mo.
Sheals, V. A., General Electric Co., Schenectady, N. Y.
Shimanovsky, Mary; res., 58 W. 127th St., New York, N. Y.
Showers, C. S., Chicago Elevated Railroads, Chicago, Ill.
Silverman, J. B., Springfield, Lt. Ht. & Pr. Co., Springfield, Ohio
Skirrow, J. F., (Member), Postal Telegraph Co., New York, N. Y.
Smith, I. C., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Smith, J. M., General Electric Co., Ft. Wayne, Ind.
Snook, H. G., General Electric Co., Chicago, Ill.
Snyder, H., Brooklyn Edison Co., Brooklyn, N. Y
Sontum, W. C., West Penn Power Co., Pittsburgh, Pa.
Stahl, B., New York Edison Co., New York, N. Y.
Stahl, C. J., Westinghouse Elec. & Mfg. Co., South Bend, Ind.
Steinbuehler, E. A., New York Edison Co., New York, N. Y.
Steiner, C. L., Jr., Bell Telephone Co. of Pa., Philadelphia, Pa.
Stratford, J. P., Cornell University, Ithaca, N. Y.
Stratton, W. M., Cia. Elec. de Alumbrado y Trac. de Santiago, Santiago, Cuba
Swanson, E. W., Electric Machinery Mfg. Co., Minneapolis, Minn.
Tates, H. W., Union Electric Construction Co., New York, N. Y.
Taylor, E. R., American Tel. & Tel. Co., New York, N. Y.
Taylor, H. S., General Electric Co., Chicago, Ill.
Thaxton, G. W., Georgia School of Technology, Atlanta, Ga.
Tinney, F. E., Wagner Electric Corp., San Francisco, Calif.

Towle, H. S., Sanitary Dist. of Chicago, Chicago, Ill.
Trainer, G. T., Pennsylvania Railroad, Philadelphia, Pa.
Vinyard, C. F., Bell Telephone Co. of Pa., Philadelphia, Pa.
von Fabrice, R., (Member), Public Service Production Co., Newark, N. J.
Waller, E., Jr., Crocker-Wheeler Co., Ampere, N. J.
Walton, C. S., Southern California Edison Co., Los Angeles, Calif.
Ward, G. C., (Member), So. California Edison Co., Los Angeles, Calif.
Wassall, C. G., Southwestern Bell Telephone Co., St. Louis, Mo.
Waugh, J. T., with T. E. Murray, Inc., New York, N. Y.
Webb, E. F., S. S. Charlton Hall, Isthmian S. S. Line, New York, N. Y.
Webster, W. C., Northwestern Electric Co., Portland, Ore.
Weil, E., Western Electric Co., Mt. Vernon, N. Y.
Weltert, J.; res., Abington Hotel, New York, N. Y.
Westervelt, C. S., D. P. Robinson & Co., New York, N. Y.
White, W. L., W. L. White & Co., Birmingham, Ala.
Wiedner, E. L., School of Engg. of Milwaukee, Milwaukee, Wis.
Wolfe, W. V., (Member), Western Electric Co., New York, N. Y.
Wood, L. A. S., (Member), Westinghouse Elec. & Mfg. Co., South Bend, Ind.
Yates, S., Adirondack Power & Light Corp., Schenectady, N. Y.
Young, R. A., Wisconsin Telephone Co., Milwaukee, Wis.
Zammataro, S. J., Western Electric Co., New York, N. Y.
Zimmerman, J. H., Westinghouse Lamp Co., New York, N. Y.
Total 231.

Foreign

Ahmed, S. M., Tata Hydro-Electric Power Supply Co., Parel, Bombay, India
Butler, P. W., Braden Copper Co., Sewell, Rancagua, Chile, S. A.
Dube, L. B., Dwarka Cement Co., Ltd., Dwarka, Kathiawar, India
Emtage, W. P., (Member), The Emtage Electrical Co., Barbados, British West Indies
Howells, E. D., State Electricity Comm. of Victoria, Melbourne, Aus.
Huggins, P., The Brush Elec. Engg. Co., Loughborough, Leicestershire, Eng.
Nylander, K. E., Board of Waterfalls, Stockholm, Sweden
Rau, R. S., Bombay Elec. Supply & Tramway Co., Ltd., Mazagaon, Bombay, India
Siraisi, H., Taiwan Electric Power Co., Taihoku City, Formosa, Japan
Sodha, N. T., The Invicta Elec. Equipment Co., Fort Bombay, India
Total 10

STUDENTS ENROLLED NOVEMBER 23, 1923

17639 Taggert, John D., University of Kentucky
17640 Fitch, Edward W., University of Kentucky
17641 Stewart, P. K., University of Kentucky
17642 Matthews, Joe E., University of Kentucky
17643 Davison, Russell H., Univ. of Nebraska
17644 Leaming, Earl K., University of Nebraska
17645 Rotkowitz, George, Columbia University
17646 Somerville, Karl R., University of Toronto
17647 Cartland, Fred W., Carnegie Inst. of Tech.
17648 Fellers, George R., Wash. State College
17649 Fosdick, Ellery R., Wash. State College
17650 Godfrey, Ceryl B., University of Texas
17651 Lander, Harold M., Univ. of New Hampshire
17652 Lindvall, Frederick C., Univ. of Illinois
17653 Nakos, Arthur J., Univ. of New Hampshire
17654 Hart, James W., University of Illinois
17655 Shively, Evert K., University of Illinois
17656 Bock, John A., University of Kansas
17657 Kennedy, Archibald R., Univ. of Kansas
17658 Manspeaker, Edwin D., Univ. of Kansas
17659 Opperman, John B., University of Kansas
17660 Benos, Leon., Mass. Inst. of Technology
17661 Davis, William R., State Col. of Wash.
17662 French, Murvin A., Northeastern Univ.
17663 Velia, Alton C., University of Notre Dame
17664 Wolf, Lester J., University of Notre Dame
17665 Duckworth, Percy H., Worcester Poly. Inst
17666 Hardy, Helen W., Mass. Inst. of Tech.
17667 Owens, Paul D., University of Delaware
17668 Whittaker, Ralph E., Mass. Inst. of Tech.
17669 Sorenson, Arthur J., State Col. of Wash.
17670 Booth, Richard P., Mass. Inst. of Tech.
17671 Backer, James J., University of Washington
17672 Misener, Louis A., Univ. of Washington
17673 Muth, Lawrence A., Univ. of Washington
17674 Kraft, Edwin A., University of Washington
17675 Walker, Richard D., Univ. of Washington
17676 Jellison, George B., Worcester Poly. Inst.
17677 Zinder, Hanina, Carnegie Inst. of Tech.
17678 Alden, Edgar, Northeastern University
17679 Bragg, Herbert E., University of Maine
17680 Broadley, William A., Northeastern Univ.
17681 O'Neil, Daniel J., Univ. of Notre Dame
17682 Pfeferholtz, Benjamin, Northeastern Univ.
17683 Vansant, Franklin T., Univ. of Delaware
17684 Krohn, Bertil W., Northeastern University
17685 Abraham, Gaylord B., Oregon Agri. College
17686 Jackson, Wayne C., Oregon Agri. College
17687 Hitzler, Benjamin L., Oregon Agri. College
17688 Shriber, William H., Oregon Agri. College
17689 Shriber, Lowell, Oregon Agri. College
17690 Flagg, Lawrence M., Oregon Agri. College
17691 Wakeman, Theodore F., Oregon Agri. Col.
17692 Siewart, Daniel R., Oregon Agri. College
17693 Coop, Edward R., Brown University
17694 Hecht, Frank J., Jr., Mass. Inst. of Tech.
17695 Mancini, John P., Penn. State College
17696 Moore, Harold D., Brown University
17697 Panton, Harry A., Penn. State College
17698 Hayne, Charles A., Cooper Union
17699 Squires, Raymond F., Cooper Union
17700 Del Duke, Venosten J., Car. Inst. of Tech.
17701 Shedd, Paul C., Worcester Poly. Institute
17702 Denison, Henry C., University of Oklahom
17703 Schlechter, Arthur H., Univ. of Oklahoma
17704 Bathe, Charles E., Univ. of Oklahoma
17705 Challenner, Ansel University of Oklahoma
17706 Hill, Murl F., University of Oklahoma
17707 Hollander, Gus M., Univ. of Oklahoma
17708 Hughes, Harold D., Univ. of Oklahoma
17709 Neal, J. Louis, University of Oklahoma
17710 Schaeffer, Hugh C., Univ. of Oklahoma
17711 Whitney, Chancy F., Univ. of Michigan
17712 McCrae, John W., Univ. of Michigan
17713 Kovach, Alexander J., Univ. of Michigan
17714 Kolb, Norman C., Univ. of Michigan
17715 Jackson, James C., Univ. of Michigan
17716 Foreman, Mahlon L., Univ. of Michigan
17717 Iler, Hobart G., University of Michigan
17718 Bibbins, Laurence W., Univ. of Michigan
17719 Borgman, William M., Jr., Univ. of Mich.
17720 Eaton, Temple O., Univ. of Wisconsin
17721 Hodges, Jesse W. P., Univ. of North Caro.
17722 Moody, John G., Mass. Inst. of Technology
17723 Reese, Sidney W., Univ. of North Carolina
17724 Rutherford, P. M., Univ. of North Carolina
17725 Davis, Edgar L., Univ. of North Carolina
17726 Trevino, Jose L., Univ. of Notre Dame
17727 Cramb, Lester P., Northeastern University
17728 Davis, Howard L., Jr., Swarthmore College
17729 Parris, Thomas, Jr., Swarthmore College
17730 Spangler, George W., Swarthmore College
17731 Keare, Spencer R., Swarthmore College
17732 Doane, Philip, Mass. Inst. of Technology
17733 Donkersley, Albert B., Mass. Inst. of Tech.
17734 Lundeen, Nelo L., Lewis Institute
17735 Pfrommer, John S., Jr., Penn. State Col.
17736 Barnett, Lewis E., Syracuse University
17737 Reynolds, Ehrman S., Syracuse University
17738 Townsend, James L., Syracuse University
17739 Hale, James E., Northeastern University
17740 Sherwood, Robert Wesley, Mass. Inst. of Tech.
17741 Speer, Grant G., Jr., Mass. Inst. of Tech.
17742 Zenlanitsky, Alexis L., Drexel Institute
17743 Meyer, William C., Lehigh University
17744 Morris, Joseph T., Yale University
17745 Tuttle, Thomas W., Mass. Inst. of Tech.
17746 Ackley, Walter T., Jr., Univ. of Pittsburgh
17747 Banks, Elbert H., University of Pittsburgh
17748 Campbell, Glenn H., Univ. of Pittsburgh
17749 Coleman, William R., Univ. of Pittsburgh
17750 Fuhrer, Raymond A., Univ. of Pittsburgh
17751 Klingensmith, Clarence L., Univ. of Pittsburgh
17752 Lehman, James N., Univ. of Pittsburgh
17753 Long, Paul B., University of Pittsburgh
17754 Ludorf, Ladislas Z., Univ. of Pittsburgh
17755 Molter, Daniel W. C., Univ. of Pittsburgh
17756 Pyle, Wilbur T., University of Pittsburgh
17757 Ralph, Clifton M., Univ. of Pittsburgh
17758 Stambaugh, Alvin C., Univ. of Pittsburgh
17759 Wasileski, Stanley H., Univ. of Pittsburgh
17760 Wills, Franklin McK., Univ. of Pittsburgh
17761 Yaeckel, Arthur T., Univ. of Pittsburgh
17762 Allen, Edward W., Jr., Univ. of Virginia
17763 Whitaker, Will A., University of Virginia
17764 Morse, Frederick T., Univ. of Virginia
17765 Scheck, Alan H., University of Virginia
17766 Mason, Joseph C., University of Virginia
17767 Jacobi, Lee R., Clemson Agri. College
17768 Wieters, Henry C., Clemson Agri. College
17769 Hall, Robert E., Clemson Agri. College
17770 Welling, Charles E., Jr., Clemson Agri. Col.
17771 Bunch, Robert L., Clemson Agri. College
17772 Cox, George W., Clemson Agri. College
17773 Ellis, Earle W., Clemson Agri. College
17774 Asbill, C. M., Jr., Clemson Agri. College
17775 Wise, George C., Clemson Agri. College
17776 Henry, Shala W., Clemson Agri. College
17777 Bell, Samuel L., Clemson Agri. College
17778 Blakeney, Lewis B., Clemson Agri. College
17779 Gillespie, Bryan B., Clemson Agri. College
17780 Cary, Francis L., Clemson Agri. College
17781 Reeve, Jack D. V., University of Colorado
17782 Bradford, William E., Univ. of Colorado
17783 Kalischer, Milton, University of Colorado
17784 Bernard, Walter, Brown University
17785 John, Stuart, Mass. Inst. of Technology
17786 Stevens, Harold C., Rutgers College
17787 Clingerman, Robert J., Bucknell Univ.
17788 Boomker, Theodore S., Armour Inst. of Tech.
17789 Gordon, Walter S., Jr., Univ. of Wash.
17790 Sletmoe, Albert M., Univ. of Washington
17791 Zobrist, Herbert E., Univ. of Washington
17792 Lewis, James W., Univ. of Washington
17793 Howe, Wilbur A., Univ. of Washington
17794 Dutton, Watson P., Union College
17795 Herz, Walter J., University of Nevada
17796 Brandt, Fred L., University of Nevada
17797 Atcheson, James C., University of Nevada
17798 Smith, Lloyd P., University of Nevada
17799 Johnson, Charles H., Univ. of Nevada
17800 Simpson, Harold L., Kansas State Agri. Col.
17801 Sherwood, Francis M., Kansas State Agricultural College
17802 Brightman, John, Kansas State Agricultural College
17803 Crockwell, Stuart H., University of Utah
17804 McPherron, Stacy, University of Utah
17805 Freeman, Stephen, Jr., Mass. Institute of Technology
17806 Thompson, Milton L., Queen's University
17807 Stoddard, Harold B., Syracuse University
17808 Haman, Otto L., University of Nebraska
17809 Johnston, Verde P., Univ. of Nebraska
17810 Mille, Ralph R., University of Nebraska
17811 Taylor, Theodore, Mass. Inst. of Tech.
17812 Rossez, Edward C., University of Nevada
17813 Olmstead, Chauncey L., Syracuse Univ.
17814 Ramsay, William F., Pennsylvania State College
17815 Morris, Edwin W., University of Nebraska
17816 Minkler, William A., California Institute of Technology
17817 Muylaert, Maurice J., California Institute of Technology
17818 Russell, George W., California Institute of Technology
17819 Lewis, William A., Jr., California Institute of Technology

17820 Pyle, Merle I., California Institute of Technology
17821 Margison, Leslie W., California Institute of Technology
17822 Morikawa, Fred M., California Institute of Technology
17823 Barcus, E. Dale, California Institute of Technology
17824 Parker, Percy E., California Institute of Technology
17825 Hamburger, Frey, California Institute of Technology
17826 Lutes, Arnold S., California Institute of Technology
17827 Walker, Rex C., California Institute of Technology
17828 Kagiwada, Frank E., California Institute of Technology
17829 Jones, Maurice T., California Institute of Technology
17830 Irwin, Emmett M., California Institute of Technology
17831 Dinsmore, Daniel G., California Institute of Technology
17832 Watkins, Robie T., California Institute of Technology
17833 Honn, Harry T., California Institute of Technology
17834 Johnson, W. Stuart, California Institute of Technology
17835 Griswold, Loys, California Institute of Technology
17836 Stone, George B., California Institute of Technology
17837 Holmes, Maurice C., West Virginia Univ.
17838 Henderson, Mahlon L., West Virginia Univ.
17839 Robinson, A. Hall, West Virginia Univ.
17840 Pitsinberger, Ira A., West Virginia Univ.
17841 Gramm, Fred W., West Virginia Univ.
17842 Jones, Edwin C., West Virginia University
17843 Naylor, Melvin, West Virginia University
17844 Davis, Charles N., West Virginia Univ.
17845 Reynolds, Franics M., West Virginia Univ.
17846 Engel, Philip M., Drexel Institute
17847 Blake, Clarence D., Northeastern Univ.
17848 Elkins, George W., Mass. Inst. of Tech.
17849 Haley, Arthur W., Worcester Polytechnic Institute
17850 Kessler, Louis W., Cooper Union
17851 Saunders, George E., University of Maine
17852 Murray, Paul R., Purdue University
17853 Brann, George E., Purdue University
17854 Guthrie, Reuel W., Purdue University
17855 Straw, Hubert D., Purdue University
17856 Watson, Maurice S., Purdue University
17857 Ankenbrandt, Otto F., Case School of Applied Science
17858 Beller, Clarence J., Case School of Applied Science
17859 Brandt, G. Herman, Case School of Applied Science
17860 Clark, Howard H., Case School of Applied Science
17861 Davis, Henry P., Case School of Applied Science
17862 Dodge, Otis L., Case School of Applied Science
17863 Geyser, George, Case School of App. Sci.
17864 Greer, Ralph R., Case School of App. Sci.
17865 Harsant, Henry J., Case School of App. Sci.
17866 Kellmer, Joseph R., Case School of Applied Science
17867 Nunn, Leonard F., Case School of Applied Science
17868 Pavlik, Chester, Case School of App. Sci.
17869 Rapport, Hyman S., Case School of Applied Science
17870 Colon, Cleo M., Georgia School of Tech.
17871 North, Henry M., Jr., Georgia School of Technology
17872 Hammond, Brett R., Georgia School of Technology
17873 Bryan, Frank C., Georgia School of Tech.
17874 Hussey, Edward O., Georgia School of Technology
17875 Hill, Harold N., Georgia School of Tech.
17876 Vick, Cecil B., Georgia School of Tech.
17877 Stark, Oliver P., Jr., Georgia School of Technology
17878 Moore, William A., Georgia School of Tech.
17879 Goodburn, Robert A., Georgia School of Technology
17880 Neighbors, George J., Georgia School of Technology
17881 Minor, John A., Georgia School of Tech.
17882 Sauer, John A., Johns Hopkins University
17883 Welsh, Robert I., John Hopkins University
17884 Hemner, Fletcher G., Mass. Inst. of Tech.
17885 Waldorf, Sigmund K., John Hopkins Univ.
17886 Hayward, Arnold P., Worcester Poly. Inst.
17887 Brown, Harold E., Univ. of North Dakota
17888 Roth, Victor M., Univ. of North Dakota
17889 Kase, J. A., Yale University
17890 Brewington, Carl W., Yale University
17891 Palmer, Glenn H., Yale University
17892 Larson, Frank A., Marquette University
17893 Welker, Clarence, Marquette University
17894 Effinger, J. Arthur, Marquette University
17895 Smith, Randolph M., Marquette Univ.
17896 Vega, Pedro J., Marquette University
17897 Armfield, Harold, Marquette University
17898 Anfang, Edward L., Marquette University
17899 Prendergast, William, Marquette Univ.
17900 Zurfluh, Joseph, Marquette University
17901 Wiest, John R., Marquette University
17902 Bergelin, Milford H., Marquette University
17903 Omiston, Thomas E., Univ. of Illinois
17904 Parker, Charles T., University of Illinois
17905 Kennedy, Robert M., Texas A. & M. Col.
17906 Wall, Charles L., Jr., Texas A. & M. Col.
17907 Forman, R. E., State Col. of Washington
17908 Stembel, David M., Univ. of Cincinnati
17909 Woodman, Charles M., Univ. of Texas
17910 Gruenberg, Anatole R., Mass. Inst. of Tech.
17911 Malinowski, Frank, Cooper Union
17912 Nash, George M., Mass. Inst. of Tech.
17913 Shoch, Clarence T., Drexel Institute
17914 James, Christ J., University of Utah
17915 Johnson, William D., Syracuse University
17916 O'Neill, Roland J., Syracuse University
17917 Kaufmann, Franklin W., Syracuse Univ.
17918 Stemwedel, Albert L., Armour Inst. of Tech.
17919 Tweedle, Charles E., Armour Inst. of Tech.
17920 Endus, L. M., Armour Inst. of Technology
17921 Sternberg, Edwin, Cornell University
17922 Palm, W. Henry, Cornell University
17923 Bromer, Edward H., Cornell University
17924 Ensor, John S., Jr., Cornell University
17925 Duryea, Hewlett H., Cornell University
17926 Kelton, Edwin C., Cornell University
17927 Jamison, Charles C., Jr., Cornell Univ.
17928 Weeden, Samuel A., Cornell University
17929 McCrea, William S., Jr., Cornell University
17930 Ballard, Thomas L., Cornell University
17931 Stein, David, Cornell University
17932 Coleman, Del Rey W., Cornell University
17933 Vanden Berghe, Willy, Cornell University
17934 Catlin, George B., Cornell University
17935 Cannon, M. K., Jr., Cornell University
17936 Brown, John J., Cornell University
17937 Hepburn, George T., Cornell University
17938 McCarthy, Albert J., Cornell University
17939 Smith, Leo C., Cornell University
17940 Van Sickle, R. C., Cornell University
17941 Severn, Orin R., Cornell University
17942 Lee, Victor, University of Utah
17943 Appleton, William E., Mass. Inst. of Tech.
17944 Slowik, Benjamin T. J., Johns Hopkins University
17945 Perry, Richard T., Mass. Inst. of Tech.
17946 Carr, James Patrick, Drexel Institute
17947 Wallace, Harry M., Montana State Col.
17948 Babbitt, Frederic, Univ. of Washington
17949 Nordahl, John G., Univ. of Washington
17950 Peterson, Howard J., Univ. of Washington
17951 Eastman, Fred S., Univ. of Washington
17952 Cohen, Philip G., Univ. of Washington
17953 Stewart, Oliver T., Univ. of Washington
17954 Woodall, Otis, University of Washington
17955 Carter, Launor McK., Univ. of Washington
17956 Kallgren, Philip A., Univ. of Washington
17957 Miller, Robert E., Univ. of Washington
17958 Cultum, Gordon L., Univ. of Washington
17959 Burk, Clarence F., Univ. of Washington
17960 Strandberg, Herbert, Univ. of Washington
17961 Roscoe, Roland T., Univ. of Washington
17962 Stahl, Chouteau P., University of Illinois
17963 Upp, Arthur, Ohio Northern University
17964 McCoombe, Charles M., Northeastern University
17965 Poteet, J. Wilmer, Johns Hopkins Univ.
17966 Kirk, Douglas, Brooklyn Poly. Inst.
17967 Wolfson, Harry, Brooklyn Poly. Inst.
17968 Barry, James M., George Washington Univ.
17969 Pim, James Harvey, George Wash. Univ.
17970 Patrick, Percy L., George Wash. Univ.
17971 McKay, Elmer C., George Wash. Univ.
17972 Straughan, T. R., Oregon Agri. College
17973 Anderson, Elmer F., Oregon Agri. College
17974 Wagner, William P., Oregon Agri. College
17975 Johnson, Elmer F., Oregon Agri. College
17976 Bennett, William R., Oregon Agri. College
17977 Milne, Donald L., Oregon Agri. College
17978 Bell, Howard E., Oregon Agri. College
17979 Hammersley, Ward, Oregon Agri. College
17980 Kellas, Alexander M., Oregon Agri. College
17981 Sutcliffe, John E., Mass. Inst. of Tech.
17982 LaBounty, Marion E., Univ. of Nebraska
17983 Mason, Ruric C., University of Arkansas
17984 Morse, Daniel S., University of Kentucky
17985 Gudgel, John W., University of Kentucky
17986 Gibson, Charles E., University of Kentucky
17987 Rankin, Russell H., Univ. of Kentucky
17988 Merrell, Harlan F., Engineering School of Milwaukee
17989 Miller, James I., Engineering School of Milwaukee
17990 Webster, Robert E., Engineering School of Milwaukee
17991 Werner, Herman J., Engineering School of Milwaukee
17992 Stewart, Halson R., Engineering School of Milwaukee
17993 Kuhn, Leonard G., Engineering School of Milwaukee
17994 Johnson, Blaine A., Engineering School of Milwaukee
17995 Groves, Cecil R., Engineering School of Milwaukee
17996 Herr, Carl E., Engineering School of Milwaukee
17997 Chromy, Ben J., Engineering School of Milwaukee
17998 Larson, Walter E., Engineering School of Milwaukee
17999 Finley, James H., Jr., Mass. Institute of Technology
18000 Wang, Tung-Chuan, Drexel Institute
18001 Manahan, William T., Johns Hopkins Univ.
18002 Jacobson, Joseph S., Johns Hopkins Univ.
18003 Mathews, Laurence E., Univ. of Nevada
18004 Ellert, Charles A., Johns Hopkins Univ.
18005 Johnson, William D., Univ. of Colorado
18006 Whitesel, Harry A., Univ. of Illinois
18007 Belk, Francis E., Univ. of North Dakota
18008 Hutcheson, John A., Univ. of North Dakota
18009 Perkins, Wallace W., University of Maine
18010 Goellner, Fred J., University of Michigan
18011 Doty, Wendell E., University of Michigan
18012 Strunk, Stanley E., University of Michigan
18013 Reid, R. Lloyd, University of Michigan
18014 Dorb, Sidney, University of Michigan
18015 Carper, Gerald I., Mass. Inst. of Tech.
18016 McDowell, David W., Drexel Institute
18017 Somerville, David J., Case School of Applied Science
18018 Walsh, Emmett J., Case School of Applied Science
18019 Gruczolowski, Anthony P., Case School of Applied Science
18020 Meister, Mike, Case School of App. Sci.
18021 Davis, Lindsey G., Case School of App. Sci.
18022 Ash, Walter B., Case School of App. Sci.
18023 Christensen, Everett F., Case School of Applied Science

Total 385

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Motors.—Booklet, 32 pp., "Electric Motors—How to Choose and Use Them." The Reliance Electric & Engineering Company, Cleveland, O.

High Tension Insulators.—Bulletin 2, Catalogue 25, 56 pp. Describes a complete line of suspension insulators, clamps and fittings. Locke Insulator Corporation, Victor, N. Y.

Transformers.—Bulletin 2028, 4 pp. Details the method of quantity production of distribution transformers. Pittsburgh Transformer Company, Pittsburgh, Pa.

Ion Concentration Meters.—Bulletin 100, 4 pp. Describes new electrical instruments for ion concentration measurements. The Brown Instrument Company, Philadelphia, Pa.

Mechanical Stoker Bulletin, 16 pp. Describes a new model multiple retort underfeed stoker. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Potential Transformer Testing Set. Bulletin 716, 12 pp. Describes a new portable instrument for testing potential transformers. The Leeds & Northrup Company, 4901 Stenton Ave., Philadelphia, Pa.

Insulating Fibre.—Booklet, 16 pp., "Fibroc Facts," describing Fibroc, a laminated phenolic condensation material, and its application for insulation purposes in the electrical field. Fibroc Insulation Company, Valparaiso, Ind.

Motors.—New price sheets on squirrel-cage induction polyphase motors, effective November 21, 1923, have been issued, superseding lists of October 1, 1923. Century Electric Company, St. Louis, Mo.

High Tension Insulators.—Catalog 19, (1924-1925) 770 pp. Porcelain insulators, trolley line materials, rail bonds and tools, third rail insulators and car equipment specialties. The Ohio Brass Company, Mansfield, Ohio.

Salinity Meters.—Bulletin 105, 4 pp. Describes new equipment for the measurement of electrolytic conductivity; surface condenser leakage, evaporator priming and boiler water salinity. The Brown Instrument Company, Philadelphia, Pa.

Commutator Stones. Bulletin, 4 pp. Illustrates a number of new style handles and additional sizes of stones for grinding commutators by hand, and describes the Imperial commutator grinding tool. The Martindale Electric Company, 11717 Detroit Ave., Cleveland, O.

Vacuum Recorder.—Bulletin 150, 4 pp. Describes a combined barometer and vacuum recorder for checking steam turbine and condenser performance, including photograph, sectional drawing and full size reproduction of actual chart. The instrument operates on the hydrostatic principle and employs no diaphragms, tube springs or multiplying lever mechanisms. Uehling Instrument Company, 473 Getty Ave., Paterson, N. J.

Lighting.—A series of instructive bulletins, issued by the Edison Lamp Works of General Electric Company, Harrison, N. J., as follows:

Lighting for Traffic Control, Bulletin 147, 32 pp., describes lighting for traffic control on land, water and in the air.

Lighting of Steel Mills and Foundries. Bulletin 150, 32 pp.

Lighting Legislation. Bulletin 148, 24 pp. Outlines state and other codes having to do with industrial and school lighting, motor vehicle regulations and the trend of probable future legislation.

Mazda Lamps in Photography. Bulletin 149, 24 pp. Describes the application of artificial light for photographic purposes.

The Lighting of Show Windows. Bulletin 103-B. Includes the data obtained from tests on the effect of intensity and color of light on the drawing power of the show window.

Lighting of Large Department Stores. Bulletin 132. The table of desirable intensity of illumination is revised; developments which have taken place in the past two years are particularly emphasized.

NOTES OF THE INDUSTRY

The General Electric Company has purchased at Los Angeles, Cal., five acres on the southwest corner of Santa Fe Avenue and 52nd Street, with a frontage of 420 ft. on Santa Fe Avenue and 520 ft. on 52nd Street. There is now located on the property a two-story reinforced concrete building which will immediately be modified and converted into a fully equipped service shop in which all kinds of electrical apparatus will be rebuilt and repaired. Later a large warehouse will be built on the property and eventually there will be a factory.

The Standard Underground Cable Company announces the following changes recently made in their Perth Amboy, N. J. organization: H. W. Fisher has been advanced in title to Technical Director of Electrical Engineering, while continuing also as Manager of Lead Cable and Rubber Departments. R. W. Atkinson has been appointed Chief Electrical Engineer. G. J. Shurts has been made Production Manager of Lead Cable Department.

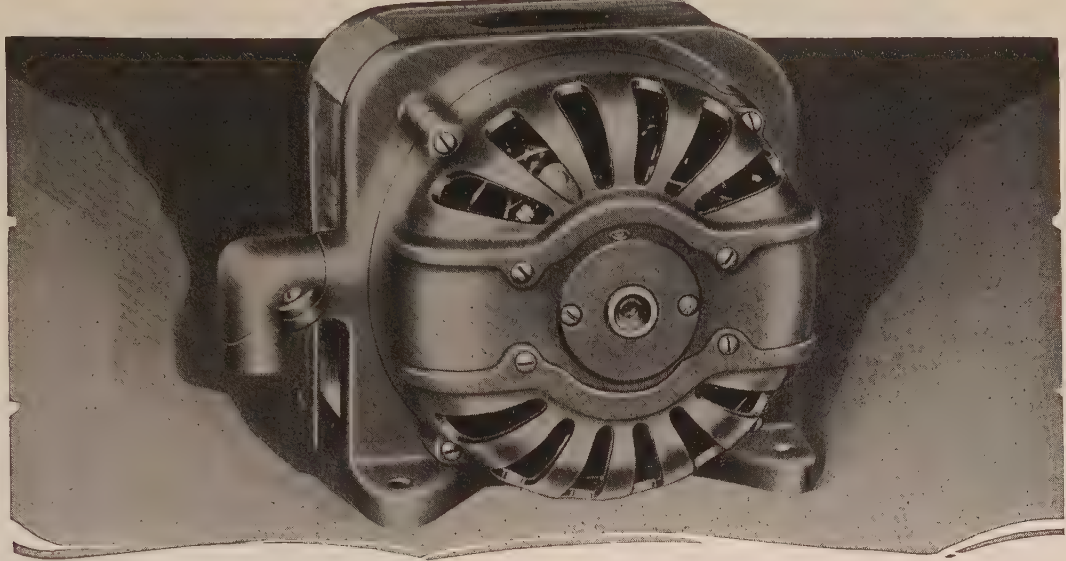
General Guy E. Tripp, Chairman of the Board of the Westinghouse Electric & Mfg. Company, has been awarded the second degree order of the Sacred Treasurer, the highest decoration that can be conferred upon a civilian foreigner by the Japanese Government. General Tripp is in Japan at the present time in connection with reconstruction work following the recent severe earthquake, and his decoration was in recognition of his activities in assisting the Japanese officials in rebuilding the devastated area.

The Schubert-Christy Construction & Machinery Company, has been organized, with offices in the Railway Exchange Building, St. Louis, Mo., by Frank H. Schubert, District Manager of the Wheeler Condenser & Engineering Co., and Wm. G. Christy, Secretary of the St. Louis Section of the A. S. M. E. In addition to representing leading manufacturers of power plant equipment the new firm will render general construction engineering service, and specialize in the design and construction of water cooling equipment for power and refrigerating plants, design of special machinery, process development and difficult construction work.

Air Cooler.—Among the products the Griscom-Russell Company, New York will exhibit at the Power Show in New York, December 3-8, is a new device, the U-fin Air Cooler, which has been developed and patented during the past year, and for which the manufacturers now have contracts under way totaling over 500,000 kw. generator ratings. The U-fin is designed for installation under the main station generator and is enclosed in the duct work. Its purpose is to cool the ventilating air discharge from the generator windings. In the past this generator air, which must be forced through the windings in order to keep them properly cooled, has been discharged in the generator room and this heat is not only lost but it has been a source of discomfort to the operating force. The U-fin cooler utilizes the turbine condensate as the cooling medium and, therefore, the heat which is extracted from the air is saved and the temperature of the turbine condensate on its way to the hot-well is increased from 8° to 10° F. The cooler is of the surface type and the cooling of the air is, therefore, accomplished in a closed system which permits the use of the same air over and over again, and, in addition, greatly reduces the fire hazard, because if a fire should occur in the generator windings, it would be quickly extinguished due to the lack of sufficient air to support combustion for any length of time


Use
KERITE
DAYS KERITE
for
signal
service
the Dictionary says:
signal (sig̃′nạl), a. Distinguished from the ordinary; extraordinary; conspicuous.
KERITE INSULATED WIRE & CABLE COMPANY
NEW YORK CHICAGO

SKF



Ball-Bearing Equipped Electric Motors

Need Attention Only 3 or 4 Times a Year

WHEN plain bearings are used on electric motors oil has to be supplied at frequent intervals and there is the ever present danger of leaking oil reaching the electrical elements and causing short circuits.

On this repulsion motor the need of attention and the risk of oil damage is reduced to a minimum by mounting the rotor on Skayef self-aligning ball bearings. This type of bearing operates in sealed housings from which the lubricant cannot escape. All the attention required is an inspection and re-lubrication of the bearings every three or four months.

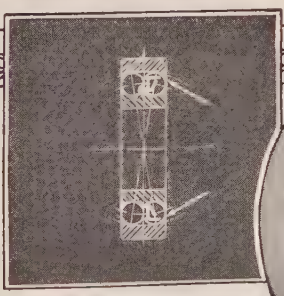
So free running is this type of bearing that no undue heating or appreciable wear occurs, the necessary clearance between the stator and rotor being maintained indefinitely without need of bearing adjustment.

Let us send you Bulletin 113 which tells about the superiority of SKF marked self-aligning ball bearings and their advantages on rotating electrical machinery.

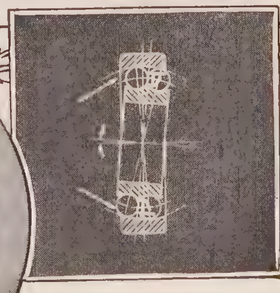
THE SKAYEF BALL BEARING COMPANY

Supervised by SKF INDUSTRIES, INC., 165 Broadway, New York City

1056



Normal View



Deflected View

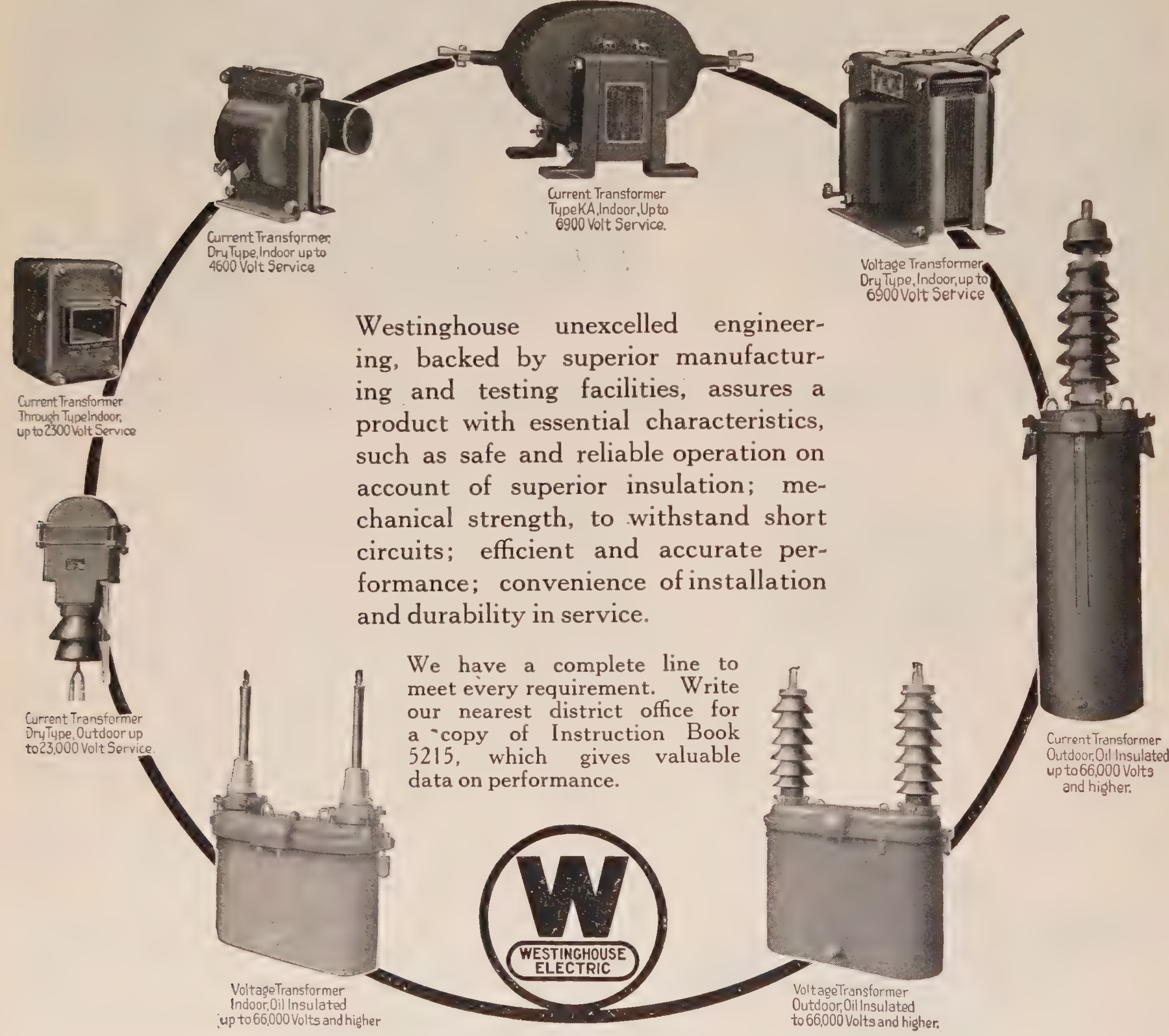
BALL BEARINGS

The Highest Expression of the Bearing Principle

8420-4

Westinghouse Instrument Transformers Are Safe, Reliable and Accurate

The safety of your transmission system, and the accuracy of your meters and instruments, depend upon the reliability of your instrument transformers

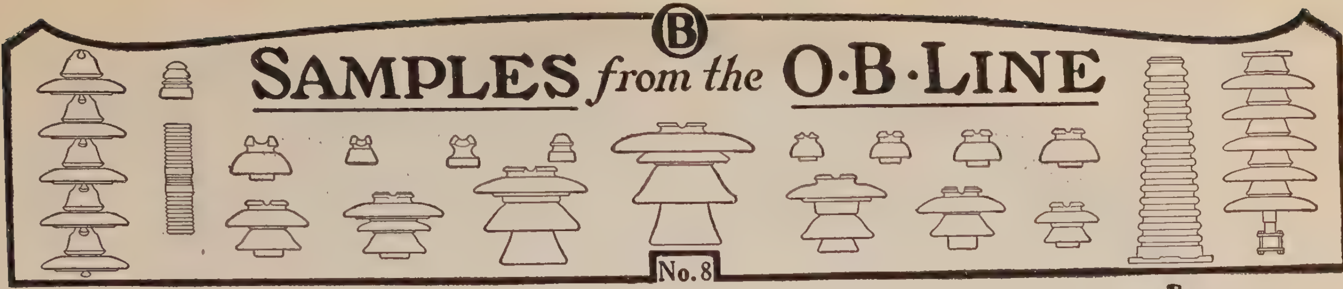


Westinghouse unexcelled engineering, backed by superior manufacturing and testing facilities, assures a product with essential characteristics, such as safe and reliable operation on account of superior insulation; mechanical strength, to withstand short circuits; efficient and accurate performance; convenience of installation and durability in service.

We have a complete line to meet every requirement. Write our nearest district office for a copy of Instruction Book 5215, which gives valuable data on performance.

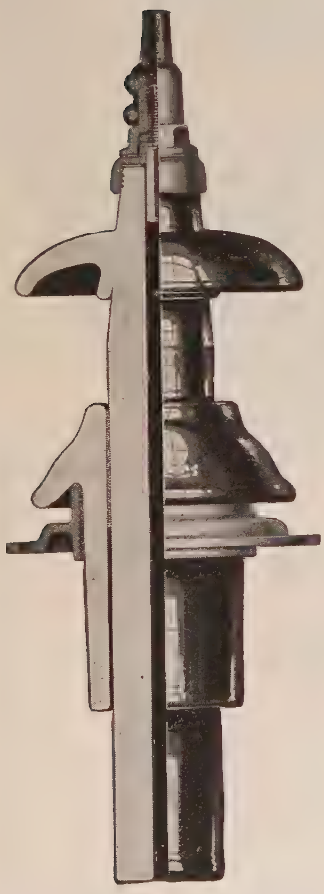
Westinghouse Electric & Manufacturing Company
Newark Works, Newark, New Jersey
Sales Offices in All Principal Cities of the United States and Foreign Countries

Westinghouse



Wall and Roof Insulators

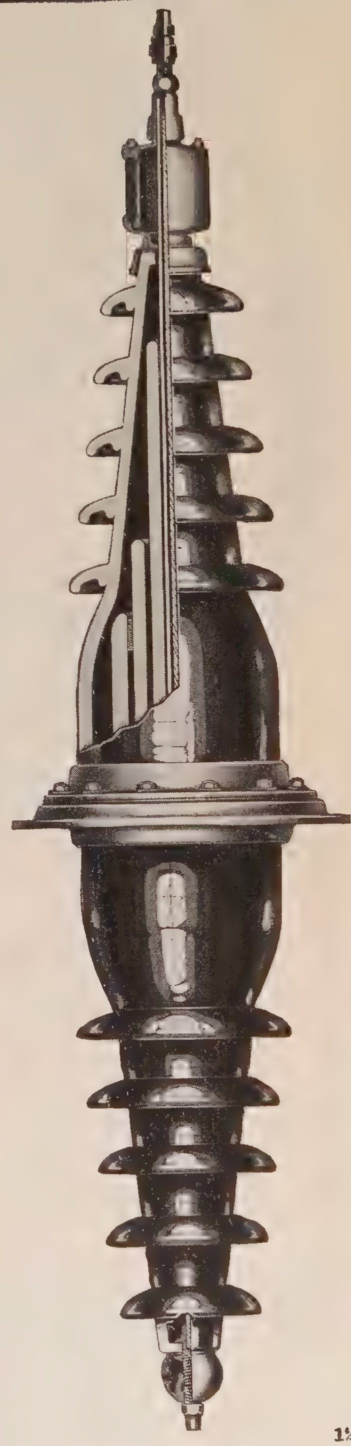
for every operating condition



TWO samples from the large line of O-B wall or roof insulators are shown on this page. On the left is an insulator of the type known at the factory as "tube bushings." These are made of one or more long porcelain tubes or sleeves, with one or more porcelain flanges or rain sheds, and are rated from 11,000 to 110,000 volts, depending on the length and number of the tubes. The insulator illustrated is rated at 33,000 volts.

On the right a "filled bushing" is shown. Insulators of this type are filled with insulating oil or compound, and are usually used for 100,000 volts or higher potentials.

Insulators of both these types are widely used for outdoor transformers and oil switches as well as for wall and roof entrance installations.

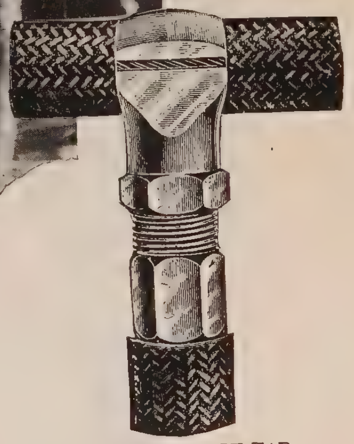


1120

The Ohio Brass Co.
Mansfield, Ohio, U.S.A.

New York Philadelphia Pittsburgh Charleston, W.Va. Chicago Los Angeles San Francisco Paris, France

Products: Trolley Material, Rail Bonds, Electric Railway Car Equipment, High Tension Porcelain Insulators, Third Rail Insulators



DOSSERT CABLE TAP

Eliminate the high cost of buses!
—*Hook up your leads to weather proof cables with a Dossert*

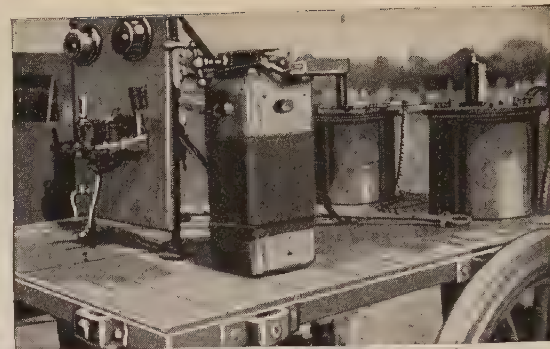
BY the use of weatherproof cables and Dossert Solderless Connectors the Consolidated Coal Company of Fairmont, West Virginia, has done away with the high cost of low tension buses in their sub-station.

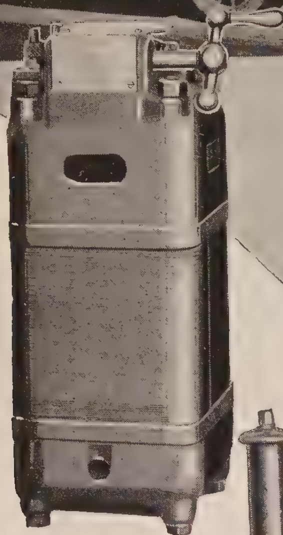
The transformer can be cleared from the main cable or connected to another quickly and easily. No further need to wind long lengths of copper around a bus. With the Dossert Connector the job of tapping is very simple, and only a short length of copper is needed.

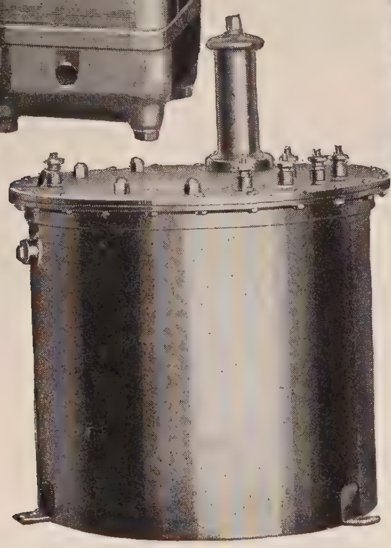
Worth your while to find out about this simple, inexpensive, labor-saving device. We'll send you particulars by return mail.

DOSSERT & CO., H. B. LOGAN, President
242 West 41st Street, New York

DOSSERT
SOLDERLESS-Connectors and Terminals







For Testing Line Insulators

Three years ago a large Western power company asked the General Electric Company to furnish a 100,000-volt, 60-cycle, portable testing set for testing the units of line insulators in the field.

As is often the case, apparatus developed for another purpose was found suitable. The problem was economically solved by using two high-voltage X-ray transformers controlled by a miniature induction voltage regulator. The power company built a trailer and mounted the apparatus, and it has tested thousands of insulator units with great satisfaction to the operating engineers.

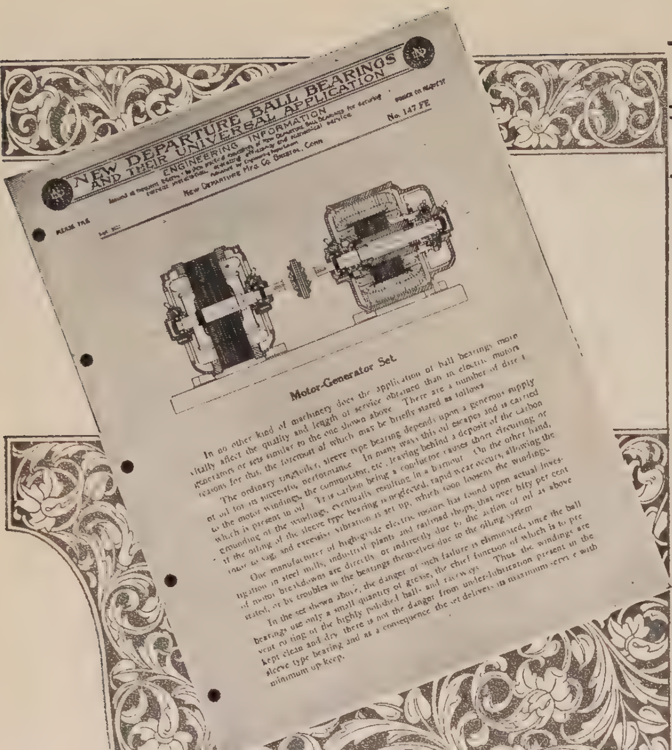
If you need testing apparatus for any purpose you will find the recommendations of our transformei engineers of value. Tell them your problems.

In addition to such portable equipment for insulator testing, there are also available a complete line of G-E high-voltage 60-cycle testing transformers and a line of high-frequency oscillator equipments.

General Electric Company
Schenectady, N. Y.
Sales Offices in all Large Cities

GENERAL ELECTRIC

33A-166



New Departure Ball Bearings

INVESTIGATION has determined that over half of electric motor breakdowns are due to lubrication troubles incidental to the use of plain bearings.

New Departure ball bearings require only a small quantity of grease, chiefly to prevent rusting of balls and raceways.

Therefore, the windings are kept dry, there is no danger of under-lubrication, and motors so equipped give the utmost in quality and length of service.

Ask for our "special bulletins on electrical machinery" with loose-leaf binder.

The New Departure Manufacturing Company
Detroit **Bristol, Conn.** **Chicago**

¶ Tantalum metal forms an electrolytic valve when used in a cell with another electrode. Tantalum is not attacked by acids or alkali solutions.

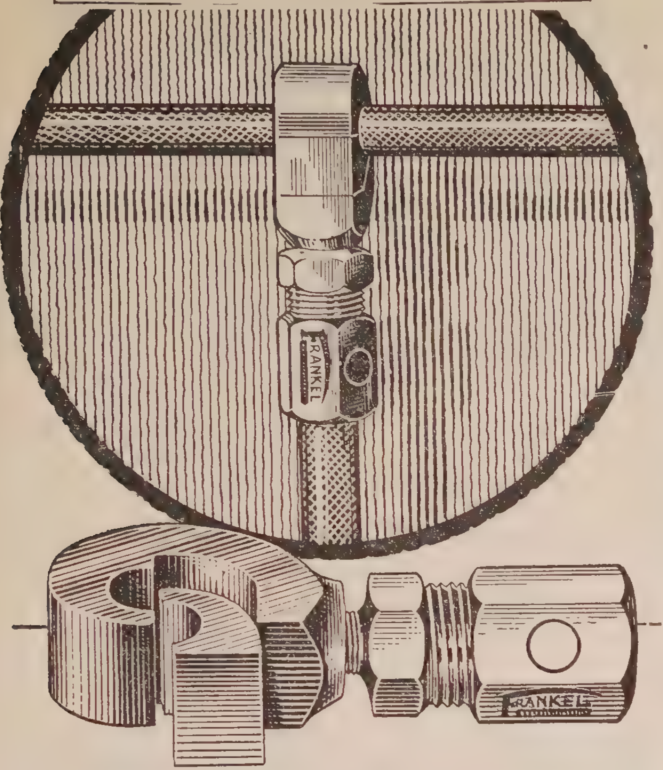
¶ Fansteel Products Company manufactures tantalum in sheets, wires and rods. Other metals manufactured by the same company which may help solve electrical difficulties are molybdenum in sheets, wires and special shapes or tungsten contact points.

¶ Fansteel tungsten contact points have been standard of quality for eight years.

Fansteel Products Company, Inc.

North Chicago **Illinois**

Frankel Patent Jan. 2, 1917



Frankel
SOLDERLESS CABLE TAPS

A splice that will stand maximum overload without injury, can be made with the Frankel Solderless Cable Tap after a study of these illustrations. Consider the economy. No solder or blow torch required. Experienced labor with attendant high cost eliminated and ten splices can be made in the time that it takes to make one soldered joint. No heat is necessary. Consequently there is no injury to the insulation on either side of the joint. Compact and neat in appearance with no loose rings to get lost. The sooner you use Frankel Solderless Cable Taps, the sooner you stop a waste of time, labor and material.

Further information upon request.

Westinghouse Electric & Mfg. Co.

or

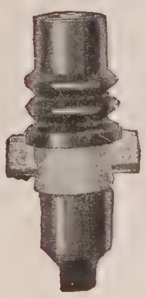
Western Electric Company

Offices in All Principal Cities of the World.

TESTS PROVE: Tensile Strength—Surface Contact—High Conductivity.

CABLE TERMINAL DEVICES

DISCONNECTING POTHEADS



The advantages of the disconnecting pothead should always be considered carefully before definite decision to use any other is made. The disconnecting feature adds little to the cost and its benefits are almost without limit, depending entirely upon the extent to which you take advantage of them.

The disconnecting pothead is the basis of a system of distribution that is more flexible than any other which could be installed or maintained or operated at anywhere near as low a cost.

Where potheads are to be installed near other manual switches the non-disconnecting pothead or plain cable seal is properly chosen, the disconnecting pothead is often used in connection with automatic switches, cutouts, etc., as it provides a disconnect which can be used in case of repairs or renewals being necessary.

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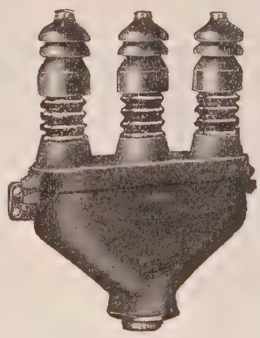
POTHEADS, DISTRIBUTION BOXES

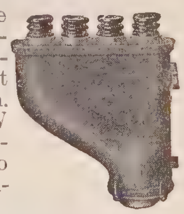


ON LINE EXTENSIONS OR IMPROVEMENTS

In planning for expansion and improvement of your distribution systems take advantage of the G and W Pothead Idea.

The value of your installation is dependent upon the adaptability of your distribution system at a time of sudden need.

Both normal conditions and the requirements of sudden demands, at a time of service interruption can be successfully met with a G and W equipped system. The experience of the G and W staff is at your service in planning complete equipment to meet the needs of specific installations.



G&W ELECTRIC SPECIALTY CO.
7440 So. Chicago Ave.
Chicago Illinois
Representatives in All Principal Cities

page 21

G & W ELECTRIC SPECIALTY CO.

The Best by Line Test

THOMAS QUALITY RELIABILITY

An American Standard Since 1873

Thomas Quality Insulators and Transmission Line Fittings

The R. Thomas and Sons Co.
East Liverpool, Ohio. U. S. A.

SALES OFFICES
New York - Boston - Chicago - London
Western Electric Co. Inc. on Pacific Coast
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LOCKE

The distribution of electrical energy is too vitally allied with the welfare of the nation to be guarded by any but the highest grade insulators.

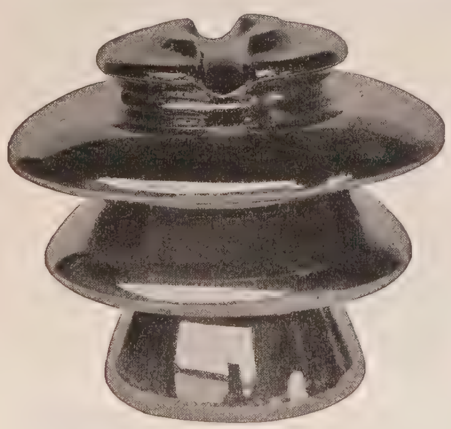
VICTOR R = ∞

Locke Insulator Corporation
Victor, N. Y.

Over a quarter of a century manufacturers of electrical porcelain for high-tension electrical power transmission.

FACTORIES
Victor, N. Y. **Baltimore, Md.**

INSULATORS



Lapp Insulators do not fail

LAPP INSULATOR CO., Inc.
LE ROY, N. Y.

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DENVER, O. H. Davidson Equipt. Co., 1633 Tremont St.
ST. LOUIS, Commercial Electrical Supply Co., Broad & Spruce Sts
MINNEAPOLIS, J. E. Sumpter Co., 222 Security Bldg.
DETROIT, F. R. Jennings Co., 805 Ford Bldg.
INDIANAPOLIS, W. D. Hamer Co., 518 Trac. Terminal Bldg.
PITTSBURGH, Union Electric Co., 933 Liberty Ave.
BUFFALO, Robertson-Cataract Electric Co.
CHARLOTTE, N. C., J. W. Fraser Co.
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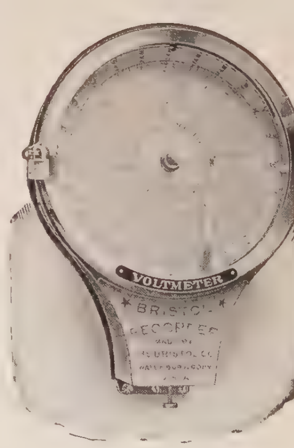
Wherever electric current is used—

In Central Stations or at the Consuming end, there is a place and need for Bristol's Voltmeters, Ammeters, Wattmeters, Milli-Voltmeters, and Shunt Ammeters. Bristol's Recording Instruments are recognized as the *Standard* throughout the world, because of their rugged construction, accurate mechanism and simplicity of operation.



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The Bristol Company
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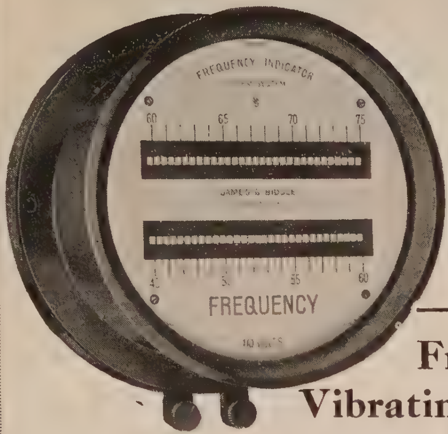
Engineers

who require the very best—

specify—



Frahm Vibrating Reed Frequency Meters

They contain no delicate springs or moving parts.

Their high initial accuracy is sustained indefinitely without recalibration.

They are *different* in design from any other frequency meter now available.

Are you thoroughly familiar with these well-known instruments?

Ask for Bulletin 995-J.

JAMES G. BIDDLE

1211-13 Arch Street, Philadelphia

Disconnecting and Heavy Duty Switches, "T&M" Switch Locks

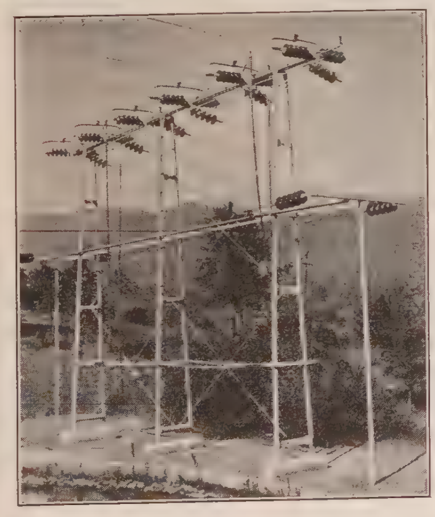
"T & M"
POTHEADS
25,000 Volts

AN end-bell that we especially recommend for indoor service. The bell is of spun copper with corrugated porcelain outlet tubes. Moderate in cost and most dependable in service.

Write for our new catalog.

Thoner & Martens

463 Commercial Street, Boston, Mass.



Simpler— Stronger— Better—

Installation K-P-F 60 KV. Switches, San Joaquin Lt. & Pwr. Corpn., Calif.

K-P-F POLE TOP SWITCHES consist of fewer parts, are more rugged and require less labor and material for installation than any other.

Each pole becomes a self-contained unit. Switches are shipped ready to bolt on to cross-arm in place of line insulator.

One crossarm supports it. Contacts are far removed from insulators and a unique device prevents sticking or freezing.

Send for bulletin K105 containing full details.

K-P-F ELECTRIC CO.

855-859 Howard St. **San Francisco**

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ON

ARISTOS "COPPERWELD" WIRE

AND ITS USES

Check the ones you wish, clip and mail to the nearest office.

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Braddock P. O., Rankin, Pa.
129 S. Jefferson St., Chicago, Ill.
403 Rialto Bldg., San Francisco, Cal.

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- [ ] Messenger, Guy and Span Wires.
- [ ] Sag and Tension Charts and Loading Tables.
- [ ] Engineering Data and Wire Tables.
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Name..

Title and Co. ....

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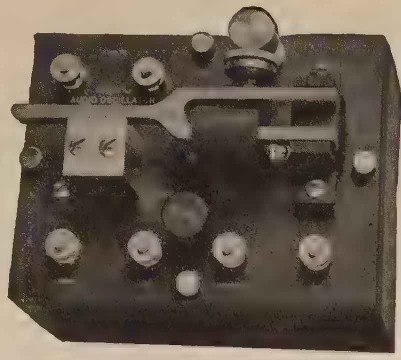


TYPE 213

1000 CYCLE OSCILLATOR

A 1000 cycle alternating current supply source for bridge and similar measurement work. Its wave form is remarkably free from harmonics, a very important feature for most alternating current bridge work.

Provision is made for output voltage of 0.5, 1.5 and 5 with corresponding currents of 100, 40 and 12 milliamperes respectively. It will operate successfully with input voltages of from 4 to 8.

Particularly adapted for college laboratories where continuous operation without attention or adjustment is desired.

Circuit Diagram and Complete Description in Bulletin 706 E.

PRICE $32.00

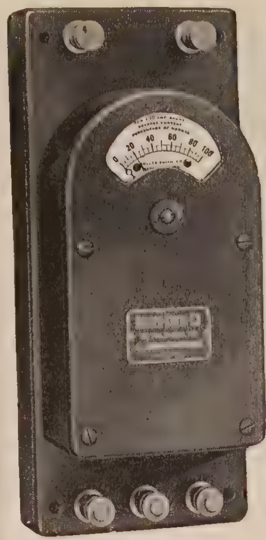
GENERAL RADIO CO.

Manufacturers of

Electrical and Radio Laboratory Apparatus

Massachusetts Avenue and Windsor Street

Cambridge 39 Massachusetts



Dimensions 9x4x2½ in.

ROLLER-SMITH "Imperial" RELAYS

For:

- Overload
- Underload
- Over-voltage
- Under-voltage
- Reverse current
- Oxygen cell work

DEPENDABLE in every sense of the word. Over twenty years' experience is built into every one.

Send for Bulletin AE-550.

ROLLER-SMITH COMPANY

Electrical Instruments, Meters and Circuit Breakers

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WORKS: Bethlehem, Penna.

Offices in Principal Cities in U. S. and Canada

The "Goodnite" Cleaning Tool.

For Clean Commutators

The "Goodnite" Cleaning Tool is designed for cleaning out commutator slots on undercut commutators.

It is useful for cleaning out carbon dust, dirt, particles of mica or other obstructions and is particularly valuable for removing burrs from the edges of the bars and for cleaning out the slots after a commutator has been turned or ground.

The distance between the blades is adjustable to correspond to the width of the commutator bars. One edge of each blade has sharp teeth to remove the obstructions, while the other edge is smooth and rides in the adjacent slot as a guide.

The blades are mounted on the holder with the teeth on opposite sides so that the tool may be used either side up. The blades are easily sharpened with a saw file.

Instructions for Use.

Having adjusted the tool for the width of the commutator bars, insert the guide and cutter in their respective slots, at the end of the commutator nearest the risers. Draw the tool smartly toward you to the end of the slot. The depth of the cut can be regulated by raising or depressing the handle.

Mail the coupon for prices and other data.

The Martindale Electric Co.,
11717 Detroit Ave., Cleveland, O.

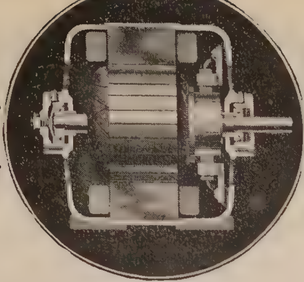
Gentlemen: Please send me complete information on the "Goodnite" Cleaning Tool and your other products.

Name..

Title..

Company..

Address..



Do Your Dealers Like to Sell Your Motors?

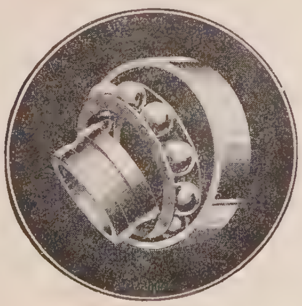
Experience shows that most of the service expense a dealer has to bear is due to motor bearing troubles on electrical utilities—the result of too much oil, or too little oil, or oil of the wrong kind.

"NORMA" PRECISION BALL BEARINGS

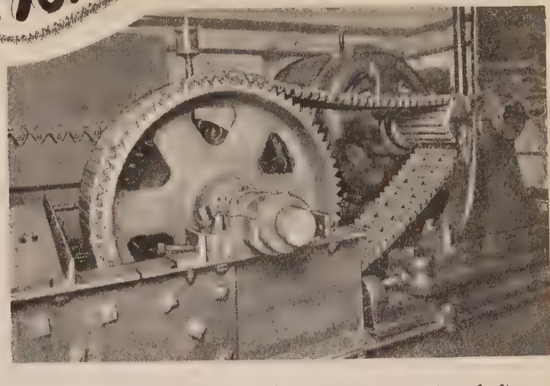
In fractional h.p. motors provide "magazine lubrication" which practically eliminates motor bearing troubles and the attendant servicing expense. And the current consumption is reduced, too —and the life of the motor increased indefinitely.

Let us send you the booklet on making good motors better

THE NORMA COMPANY OF AMERICA
Anable Avenue
Long Island City New York
BALL, ROLLER AND THRUST BEARINGS



MORSE SILENT CHAIN DRIVES



75 H. P. Morse Drives from motor to center shaft to ammonia compressor, Swift & Co., Brooklyn, N. Y.

Transmitting the full power and protecting your motor

The motor may be powerful and efficient, but nevertheless have its good work nullified by an inefficient drive.

Morse Silent Chain Drives transmit 98.6% of the power developed, with positive fixed speed ratio between driver and the driven over short or long center distances.

In addition, they have sufficient flexibility to protect the motor from shocks and vibrations, insuring against bearing trouble. They save substantially in the cost of motor upkeep.

Morse Silent Chains, therefore, transmit the full power of your motor, and insure its continued efficiency and long life through absorption of operating shocks and vibrations.

Morse Engineers are at your service—they will gladly give you their experience in applying Morse Silent Chains to transmission problems of all sorts.

2065-30

MORSE CHAIN CO., ITHACA, N.Y.

There is a Morse Engineer near you

ATLANTA, GA.	DENVER, COLO.	PHILADELPHIA, PA.
BALTIMORE, MD.	DETROIT, MICH.	PITTSBURGH, PA.
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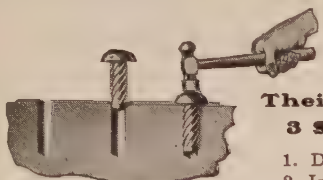
Better and Stronger Fastenings to Steel, Cast Iron, Bakelite, Fibre, etc., are made with

Parker-Kalon
Hardened Metallic
Drive Screws
(Patented)

More than 2000 manufacturers use them in place of escutcheon pins, machine screws, etc., for fastening name plates and making permanent assemblies.



They Eliminate the Costly Tapping Operation

Their Use Involves But 3 Simple Operations

1. Drill a hole.
2. Insert the tip of Screw.
3. Drive in with a hammer.

As easy as driving a nail — anyone can do the job.

Investigate their time - and - labor - saving possibilities

Write for samples today!

PARKER - KALON CORP., *Patentees*
358 West 13th St. NEW YORK
Agents for British Isles:
Chas. Churchill & Co., Ltd., Finsbury, London, E. C. 2, England

The Highest Development of Vulcanized Cotton Fibre

It has taken nearly a half a century to produce Vul-Cot Fibre—a half century of study and experiment to produce material of exceeding toughness and hardness and that is not brittle.

Vul-Cot is made by the oldest and largest manufacturer of Vulcanized Fibre in the country. Every detail, every process in the manufacturing of Vul-Cot Fibre is performed in the three huge plants of the National Vulcanized Fibre Company.

The result is a Fibre that is three times as tough as leather. No ordinary force can crush, break, crack or split it. Its tensile strength is from 9,000 to 14,000 pounds per square inch, with a resistance to shearing up to 13,000 pounds per square inch, and an electrical rupture up to 400 volts per mil.

We have made Vul-Cot Fibre with such care, with such minute attention to every detail, that we can guarantee it to be free from impurities.

If there is a place for fibre in the composition of your product—if there is a possibility for a material that is hard as horn, as durable as steel, as adaptable as rubber and yet less costly than any—we will gladly place at your disposal the experience gained through years of making parts for the products of the host of manufacturers who use Vul-Cot Fibre.

National Vulcanized Fibre Company
Wilmington, Del.

Use Diamond Fibre

Wherever the job in hand demands a tough, service-giving material of great strength, light weight and high dielectric qualities, use Diamond Fibre. We produce this remarkable raw material in easy-to-handle

SHEETS - RODS - TUBES

ready for all machining processes or fully machined to your own specifications. Write for samples and full information.

Diamond State Fibre Company
Bridgeport (near Philadelphia), **Pa.**
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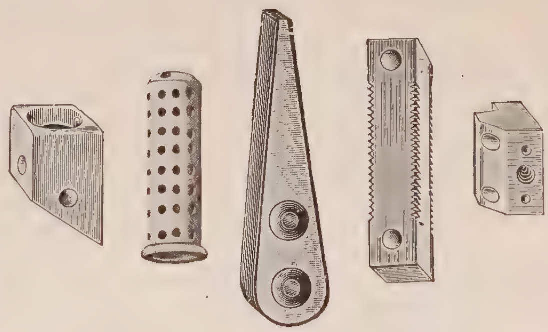
PENNSYLVANIA ELECTRICAL SLATE
for
Switchboards, Panelboards, Fuse Blocks, Bus Bar Supports, etc.

THE STRUCTURAL SLATE CO.
118 Robinson Avenue, Pen Argyl, Penna.
Comprehensive Data on Electrical, Chemical and Physical Properties of Pennsylvania Slate sent on request

LAVA INSULATORS



Unchanging Durable
Always Uniform

LAVA has unlimited application in the construction of electrical appliances and heating apparatus.

Write our engineering department.

AMERICAN LAVA CORPORATION
27-67 Williamson Street
CHATTANOOGA, TENNESSEE
Manufacturers of Heat-Resistant Insulators

(Cards continued on next page)

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Manufacturers and agents for machinery and supplies used in the electrical and allied industries.

Note: For reference to the advertisements see the Alphabetical List of Advertisers on page 42.

AIR COMPRESSORS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities

AIR COMPRESSOR FILTERS
Midwest Air Filters, Inc., New York

AIR FILTERS, CLEANERS, CONDITIONERS
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Spray Engineering Co., Boston.
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AMMETERS, VOLTMETERS
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General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

BEADS, INSULATING
Martindale Electric Co., The, Cleveland

BEARINGS, BALL
New Departure Mfg. Co., The, Bristol, Conn.
Norma Co. of America, L. I. City, N. Y.
S K F Industries, New York

BOOKS, TECHNICAL
Wiley & Sons, Inc., John, New York

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General Electric Co., Schenectady, N. Y.
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

BOXES, JUNCTION
G & W Elec. Specialty Co., Chicago
Metropolitan Device Corp., Brooklyn, N. Y.
Standard Underground Cable Co., Pittsburgh

BRAKES, CAR
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.

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Morganite Brush Co. Inc., New York
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Copper Graphite
Morganite Brush Co. Inc., New York
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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Minerallac Electric Co., Chicago
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Western Electric Co., All Principal Cities

CABLES
(See WIRES AND CABLES)

CABLEWAYS
Roebling's Sons Co., John A., Trenton, N. J.

CAMBRIC, VARNISHED
Irvington Varnish & Ins. Co., Irvington, N. J.

CARBON BRUSHES
(See BRUSHES COMMUTATOR)

CHAINS, POWER TRANSMISSION
Morse Chain Co., Ithaca, N. Y.

CIRCUIT BREAKERS
Condit Electrical Mfg. Co., So. Boston, Mass.
General Electric Co., Schenectady, N. Y.
Pacific Electric Mfg. Co., San Francisco
Roller-Smith Co., New York
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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Cutler-Hammer Mfg. Co., Milwaukee

COILS, MAGNET
Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago, Ill.
Dudlo Mfg. Co., Ft. Wayne, Ind.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONDENSATION PRODUCTS
Bakelite Corporation, New York
Condensite Co. of America, Bloomfield, N. J.
General Bakelite Co., New York
Redmanol Chemical Products Co., Chicago

CONDENSERS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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Western Electric Co., All Principal Cities

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Frankel Connector Co., Inc., New York
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONNECTORS AND TERMINALS
Dossert & Co., New York
G & W Electric Specialty Co., Chicago, Ill.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONTACTS, TUNGSTEN
Fansteel Products Co. Inc., North Chicago, Ill.
General Electric Co., Schenectady, N. Y.

CONTROLLERS
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General Electric Co., Schenectady, N. Y.
Rowan Controller Co., Baltimore
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Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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Allis-Chalmers Mfg. Co., Milwaukee
Northwestern Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

COOLING AIR FILTERS
Midwest Air Filters, Inc., New York

COOLING PONDS
Spray Engineering Co., Boston

COPPER CLAD WIRE
Copper Clad Steel Co., Rankin, Pa.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

CUT-OUTS
Condit Electrical Mfg. Co., S. Boston, Mass
General Electric Co., Schenectady, N. Y.
G & W Electric Specialty Co., Chicago
Johns-Pratt Co., Hartford, Conn.
Metropolitan Device Corp., Brooklyn, N. Y.
Thoner & Martens, Boston
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

DRAWING MATERIALS
Keuffel & Esser Company, Hoboken, N. J.

DYNAMOS
(See GENERATORS AND MOTORS)

ELECTRIFICATION SUPPLIES, STEAM ROAD
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, Ohio
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

ENGINEERS, CONSULTING AND CONTRACTING
Stone & Webster, Inc., Boston
(See also PROFESSIONAL ENGINEERING DIRECTORY)

ENGINES *Gas & Gasoline*
Allis-Chalmers Mfg. Co., Milwaukee
Oil
Allis-Chalmers Mfg. Co., Milwaukee
Steam
Allis-Chalmers Mfg. Co., Milwaukee

FANS, MOTOR
Century Electric Co., St. Louis
General Electric Co., Schenectady, N. Y.
Star Electric Motor Co., Newark, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

FARM LIGHTING GENERATORS
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

FIBRE
Diamond State Fibre Co., Bridgeport, Pa.
National Vulcanized Fibre Co., Wilmington, Del.

FILTERS, AIR
(See Air Filters)

FURNACES, ELECTRIC
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

FUSES *Enclosed Refillable*
General Electric Co., Schenectady, N. Y.
Johns-Pratt Co., Hartford, Conn.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Enclosed Non-Refillable
General Electric Co., Schenectady, N. Y.
Johns-Pratt Co., Hartford, Conn.
Western Electric Co., All Principal Cities
Open Link
General Electric Co., Schenectady, N. Y.
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
High Tension
Metropolitan Device Corp., Brooklyn, N. Y.
Railway & Industrial Engg. Co., Greensburg, Pa.
Western Electric Co., All Principal Cities

GEARS, FIBRE
Diamond State Fibre Co., Bridgeport, Pa.
General Electric Co., Schenectady, N. Y.
National Vulcanized Fibre Co., Wilmington, Del.

GENERATORS AND MOTORS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Century Electric Co., St. Louis Mo.
Electro-Dynamic Co., Bayonne, N. J.
General Electric Co., Schenectady, N. Y.
Northwestern Electric Co., Chicago
Star Electric Motor Co., Newark, N. J.
Sturtevant Company, B. F., Boston, Mass.
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

GENERATING STATION EQUIPMENT
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

GRINDERS, COMMUTATOR
Martindale Electric Co., The, Cleveland

GROUND RODS
Copper Clad Steel Co., Rankin, Pa.
Western Electric Co., All Principal Cities

HEADLIGHTS
Ohio Brass Co., Mansfield, O.

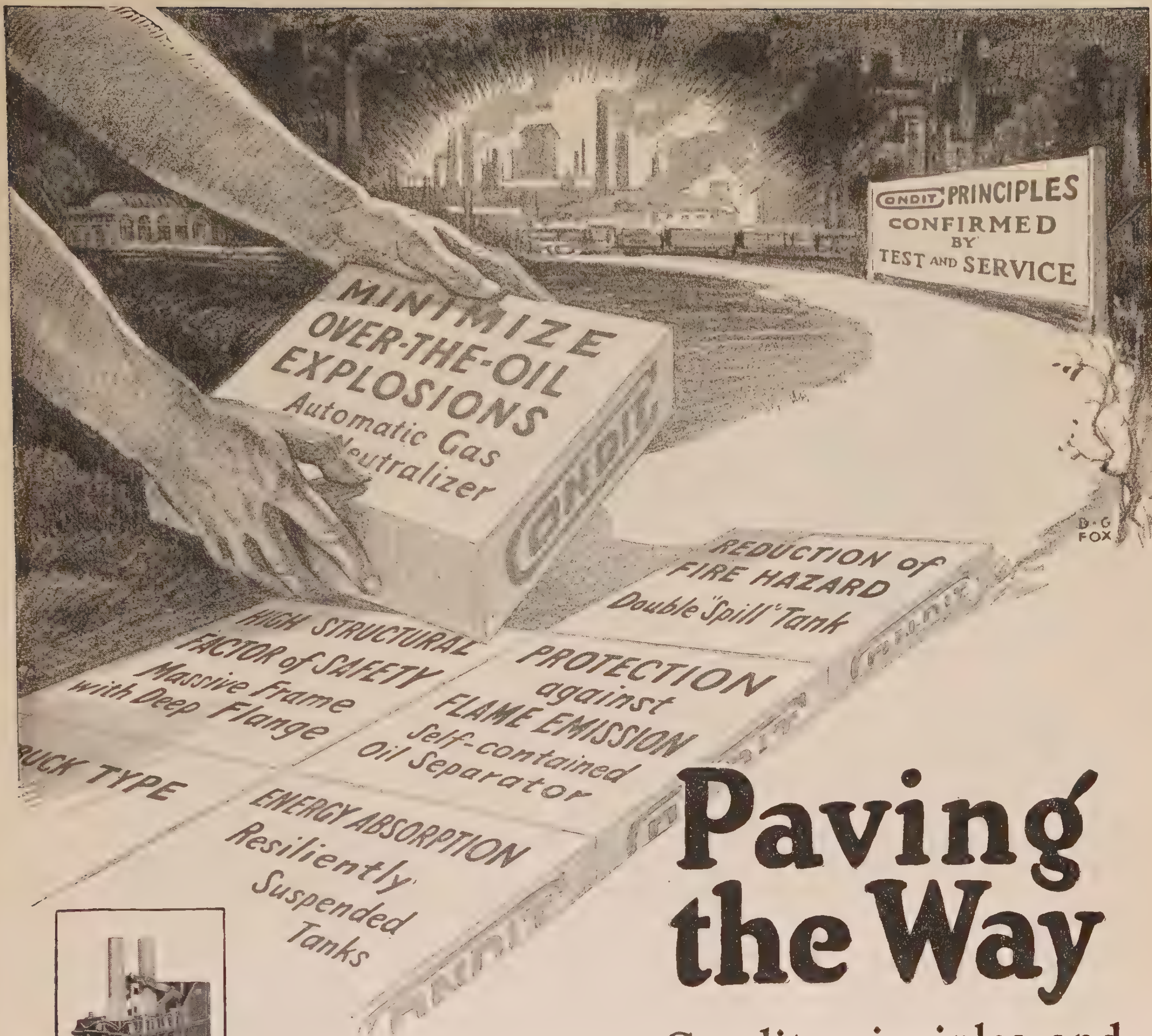
HEATERS, INDUSTRIAL
Cutler-Hammer Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

HEATING & VENTILATING EQUIPMENT
Midwest Air Filters, Inc., New York

INDICATORS, SPEED
Biddle, James G., Philadelphia
Roller-Smith Co., New York

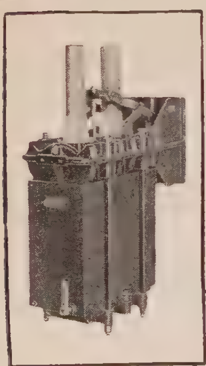
INSTRUMENTS, ELECTRICAL
Graphic
Biddle, James G., Philadelphia
Bristol Co., The, Waterbury, Conn.
Ferranti, Ltd., London, Eng.
General Electric Co., Schenectady, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Indicating
Ferranti, Ltd., London, Eng.
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Integrating
Biddle, James G., Philadelphia
Duncan Elec. Mfg. Co., Lafayette, Ind.
Ferranti, Ltd., London, Eng.
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York
Sangamo Elec. Co., Springfield, Ill.
States Co., The, Hartford, Conn
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Repairing and Testing
Electrical Testing Laboratories, New York
Scientific, Laboratory, Testing
Biddle, James G., Philadelphia
General Electric Co., Schenectady, N. Y.
Leeds & Northrup Co., Philadelphia
Metropolitan Device Corp., Brooklyn, N. Y.
Roller-Smith Co., New York
States Co., The, Hartford, Conn.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Telegraph
Western Electric Co., All Principal Cities
Wireless
Acme Apparatus Co., Cambridge, Mass.
General Radio Co., Cambridge, Mass.

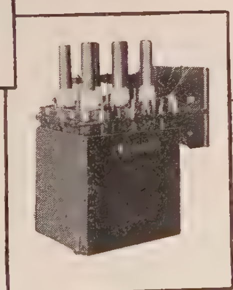
INSULATING MATERIALS
Cloth
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Composition
Bakelite Corporation, New York
Belden Mfg. Co., Chicago
Condensite Co. of America, Bloomfield, N. J.
Cutler-Hammer Mfg. Co., Milwaukee
General Bakelite Co., New York
Hopewell Ins. & Mfg. Co., Hopewell, Va.
Redmanol Chemical Products Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Compounds
Minerallac Electric Co., Chicago
Standard Underground Cable Co., Pittsburgh
Sterling Varnish Co., Pittsburgh
Western Electric Co., All Principal Cities
Fibre
Diamond State Fibre Co., Bridgeport, Pa.
Lava
American Lava Co., Chattanooga, Tenn.

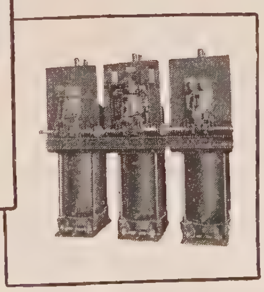


Paving the Way

Condit principles and Condit service are paving the way toward more efficient service in industrial plants and central stations.


Single Unit


Common Frame


Truck Type

CONDIT ELECTRICAL MFG. CO.
Manufacturers of Electrical Protective Devices
South Boston, Mass.

Northern Electric Company
LIMITED
Sole Distributor for the Dominion of Canada

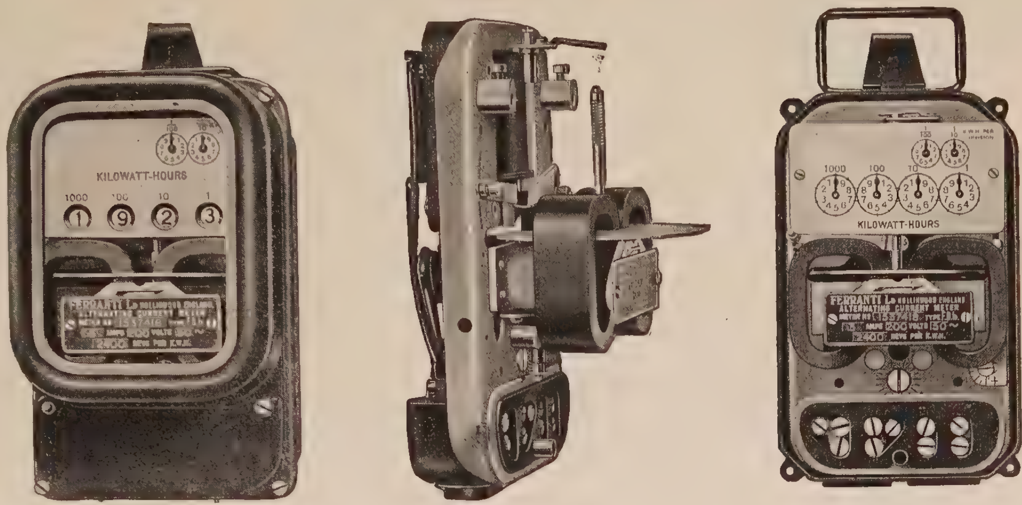
6039

CONDIT

Classified Advertiser's Index for Buyers—*Continued*

FERRANTI

A. C. METER. TYPE FDb.



1. The material used is the finest obtainable.
2. The workmanship is of the highest standard.
3. The design incorporates intensive knowledge acquired during 40 years of meter building, in co-operation with users throughout the world.

TECHNICAL DATA

Torque. 5 gram-centimetres.

Weight of Rotor. 13 grams.

Speed at full load. 40 revs. per minute.

Starting Watts. 0.5% of rated full load at unity power factor.

Shunt Loss. 1.5 watts.

Series Loss. 1 watt at rated current.

Changes due to variation of **Voltage, Frequency** and **Temperature** are negligible.

Weight. $4\frac{1}{4}$ lbs.
1.93 kg.

Overall Dimensions. $6\frac{9}{16}$ inches $\times$ $3\frac{15}{16}$ inches $\times$ $3\frac{3}{16}$ inches.
167 mm. $\times$ 100 mm. $\times$ 81 mm.

Cost of Transport to any port in the world does not exceed 6 d.

FERRANTI, LIMITED

HOLLINWOOD, LANCASHIRE, ENGLAND

CANADIAN HEAD OFFICE AND FACTORY:

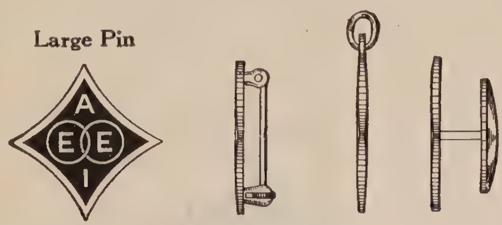
Ferranti Meter & Transformer Manufacturing Co. Ltd., 26 Noble Street, Toronto

BRANCHES: Montreal, Winnipeg, Halifax, Timmins, Calgary

A. I. E. E. MEMBERSHIP BADGES

STYLES OF BADGES

Large Pin



ACTUAL SIZE — Vest Pin — Charm — Button (solid back)

Small Pin

ACTUAL SIZE — Vest Pin — Scarf Pin — Button (screw back)

PRICES OF BADGES

Size	Style Back	Price	Style No.
Large	Vest Pin	$4.50	1
Large	Charm	4.50	2
Large	Lapel Button (Solid Back)	6.00	3
Small	Vest Pin	3.00	4
Small	Scarf Pin	3.50	5
Small	Lapel Button (Plated Screw Back)	3.00	6

THE membership of the Institute is privileged to wear the official badge of the society in the various styles shown herein.

All the membership badges are of solid 14k gold, excepting the small size lapel button, the screw back of which is of plated gold. The enameled background is maroon for Associates and blue for Members, with letters and border in gold. The Fellow badge is the reverse in color of that provided for Members.

Upon transfer to the Member grade an Associate badge (large size only) can be reenameled blue at a cost of $1.00. The small badges and the large size Member badges cannot be reenameled; a credit of $.75 for a small badge and $1.00 for a large badge ($1.25 for large lapel button) will be allowed, however, upon the return of a badge to Institute Headquarters, to apply as part payment for a new badge. This credit is also allowed to those members who desire to exchange a large size badge for the smaller size.

Orders for badges should be accompanied by remittance and should indicate Badge Style Number (see price-list) desired.

American Institute of Electrical Engineers
33 West 39th Street, New York

Classified Advertiser's Index for Buyers—*Continued*

TROLLEY LINE MATERIALS
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TURBINES, HYDRAULIC
Allis-Chalmers Mfg. Co., Milwaukee
Cramp & Sons Ship & Engine Bldg. Co., The Wm., Philadelphia

TURBINES, STEAM
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
General Electric Co., Schenectady, N. Y.
Sturtevant Company, B. F., Boston, Mass.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TURBO-GENERATORS
Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

VALVES
Johnson Hydraulic
Cramp & Sons Ship & Engine Bldg. Co., The Wm., Philadelphia

VARNISHES, INSULATING
General Electric Co., Schenectady, N. Y.
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

WELDING EQUIPMENT, ELECTRICAL
General Electric Co., Schenectady, N. Y.
Ohio Brass Co., Mansfield, O.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

WIRELESS APPARATUS
Acme Apparatus Co., Cambridge, Mass.
General Radio Co., Cambridge, Mass.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

WIRES AND CABLES
Armored Cable
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Asbestos Covered
Belden Mfg. Co., Chicago
General Electric Co., Schenectady, N. Y.
Rockbestos Products Corp., New Haven Conn.

Auto
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Bare Copper
American Ins. Wire & Cable Co., Chicago
Anaconda Copper Mining Co., Chicago
Belden Mfg. Co., Chicago
Copper Clad Steel Co., Rankin, Pa.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Copper Clad
Copper Clad Steel Co., Rankin, Pa.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Flexible Cord
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Fuse
General Electric Co., Schenectady, N. Y.
Roebling's Sons Co., John A., Trenton, N. J.
Western Electric Co., All Principal Cities

Lead Covered (Paper and varnished cambric insulated)
Atlantic Ins. Wire & Cable Co., Stamford, Conn.
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

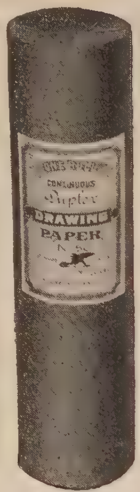
Magnet
Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago
Dudlo Mfg. Co., Fort Wayne, Ind.
General Electric Co., Schenectady, N. Y.
Rockbestos Products Corp., New Haven, Conn.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Rubber Insulated
Atlantic Ins. Wire & Cable Co., Stamford, Conn.
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Trolley
Anaconda Copper Mining Co., Chicago
Copper Clad Steel Co., Rankin, Pa.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Weatherproof
American Ins. Wire & Cable Co., Chicago
Copper Clad Steel Co., Rankin, Pa.
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston, Mass.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

When extra strength is needed—



Drawings that must stand a lot of handling or serve as permanent record, should not be put on anything but a ***tough, all-rag paper*** such as

"DUPLEX"

Drawing Paper No. 50

The best all-around drawing paper. Its price is only slightly higher than that of inferior semi-wood pulp papers that do not approach its qualities. Here are some of the reasons for "Duplex" popularity:

—does not become brittle with age;
—stands as many as six knife erasures;
—its *buff* color allows of handling without soiling;
—always flat, never wrinkles.

In rolls and sheets up to 62 in. wide.

Water-marked along the edge: "DUPLEX."

Sample and price upon application.

Buy it in original rolls by the pound!

KEUFFEL & ESSER CO.

NEW YORK, 127 Fulton Street, General Office and Factories, HOBOKEN, N. J.

CHICAGO 616-20 S. Dearborn St. ST. LOUIS 817 Locust St. SAN FRANCISCO 30-34 Second St. MONTREAL 5 Notre Dame St. W.

Drawing Materials, Mathematical and Surveying Instruments, Measuring Tapes

BAKELITE

The entire case and binding post caps of this Weston Wattmeter are molded of Bakelite

The modern art of electrical measuring was created by Dr. Edward Weston. Bakelite was used first by him for such delicate purposes.

Bakelite is admirably suited for use in electrical precision instruments for it permits refinement of design and combines the properties of high dielectric and mechanical strength together with resistance to oil, moisture, heat, and most chemicals.

Our research department offers cooperation.

BAKELITE Condensite *REDMANOL* are the registered Trade Marks for the Phenol Resin Products manufactured under patents owned by BAKELITE CORPORATION

BAKELITE CORPORATION
247 Park Avenue, New York, N.Y.

Plants
Perth Amboy N. J. — 636 W. 22d St. Chicago, Ill.
Bloomfield, N.J. — Painesville, Ohio

THE MATERIAL OF A THOUSAND USES

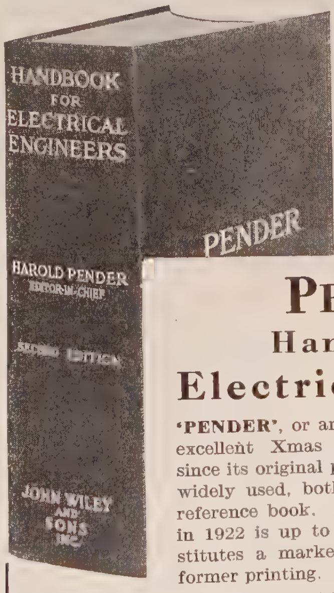
MARINE RULES

Recommended Practise for Electrical Installations on Shipboard

THE Marine Rules have been drawn up to serve as a guide for the equipment of merchant ships with electrical apparatus for lighting, signaling, communication and power, but not including propulsion. They indicate what is considered the best engineering practise with reference to safety of the personnel and of the ship itself, as well as reliability and durability of the apparatus. These rules are intended to supplement the STANDARDS of the A. I. E. E., which should be followed wherever applicable.

Linen covered, 97 pp., price, $1.00 per copy, with discount of 25% to members of the A. I. E. E., dealers, and purchasers of ten or more copies.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
33 West 39th Street, New York



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'PENDER', or any other Wiley book, makes an excellent Xmas gift for any engineer. Ever since its original publication, in 1914, it has been widely used, both in the field and as an office reference book. The Second Edition, published in 1922 is up to date in every respect, and constitutes a marked improvement even over the former printing.

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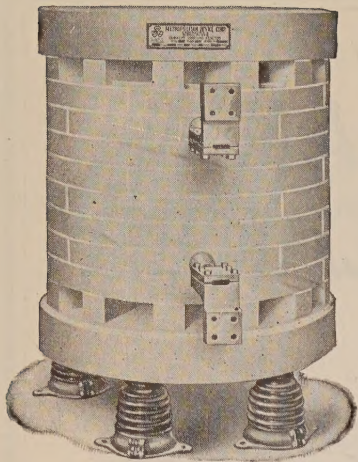
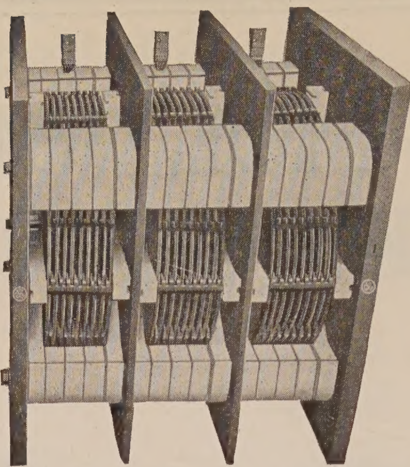
ALPHABETICAL LIST OF ADVERTISERS

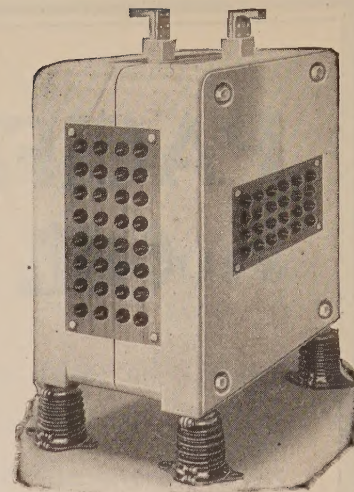
(For classified list of Advertisers see pages 36, 38 and 40)



Indoor service
350 to 750 Amp.



Three-phase Feeder Coil



Indoor service 25 to 350 Amp.

Three Real Headliners

When a central station manager is in doubt as to the kind of current limiting reactors to install—it is a good idea to check up what equipment is used by the greatest and most economical generating plants in this country.

Metropolitan Reactors, for instance, are used by the big Edison Companies in NewYork, Boston, Chicago, Detroit, Brooklyn, etc. Also they are standard equipment not only in the central station but in the industrial field as well.

Short circuits cannot be prevented as yet, but you can do the next best thing, install Metropolitan Reactors and protect your equipment from abnormal and dangerous stresses. Investigate today.

Partial List of Installations of Metropolitan Reactors

Edison Elec. Illuminating Co.	Boston, Mass.
Brooklyn Rapid Transit Co.	Brooklyn, N. Y.
Calgary Municipal Electric Co.	Calgary, Canada
Canadian Niagara Falls Power Co.	Niagara Falls, Ont.
Cataluna Power Co.	Barcelona, Spain
Chicago, Lake Shore & South Bend R. R.	Michigan City, Ind.
Cohoes Light & Power Corp.	Cohoes, N. Y.
Commonwealth Edison Co.	Chicago, Ill.
Consolidated Gas & Electric Co.	Baltimore, Md.
Dayton Power & Light Co.	Dayton, Ohio
East Hampton Gas Co.	East Hampton, Mass.
Edison Electric Illuminating Co.	Brooklyn, N. Y.
Edison Illuminating Co.	Detroit, Mich.
El Paso Power & Railroad Co.	El Paso, Texas
French General Electric Co.	Paris, France
Hydro Electric Power Commission	Toronto, Ontario
Havana Elec. Ry. Lt. & Pwr. Co.	Havana, Cuba
Interborough Rapid Transit Co.	New York, N. Y.
Joyce Gridland Railroad Co.	London, England
Municipal Gas Co.	Albany, N. Y.
New York Edison Company	New York, N. Y.
N. Y., N. H. & H. R. R. Co.	West Farms, N. Y.
N. Y. & Queens Elec. Light & Power Co.	Long Island City, N. Y.
Potomac Electric Co.	Washington, D. C.
Public Works Department	Lake Coleridge, N. Z.
Public Service Electric Co.	Newark, N. J.
Shawinigan Hydro Elec. Power Co.	Shawinigan Falls, Ont.
Tennessee Power Co.	Chattanooga, Tenn.
Toledo R. R. & Light Co.	Toledo, Ohio
Toronto Power Co.	Niagara Falls, Ont.
Turners Falls Power Co.	Turners Falls, Mass.
United Electric Lighting Co.	Springfield, Mass.
United Electric Light & Power Co.	New York, N. Y.
Union Gas & Electric Co.	Cincinnati, Ohio
Union Electric Lt. & Pwr. Co.	St. Louis, Mo.
U. S. Explosive Plant	Nitro, West Va.
Utica Gas & Electric Co.	Utica, N. Y.
Victoria Falls & Transvaal P. Co.	Simmerpan, South Africa
Warren & Co.	Boston, Mass.
Westchester Lighting Co.	Mount Vernon, N. Y.
Youngstown Sheet & Tube Co.	Youngstown, Ohio

Metropolitan Device Corporation

1250 Atlantic Avenue, Brooklyn, N. Y.